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MINING GEOLOGY: RETROSPECT AND PROSPECT[1]

HUGH McKINSTRY

ABSTRACT

During the past half-century geology has gained acceptance as a valuable if not indispensable aid in finding and developing orebodies, thanks to improved methods of applying the science as well as to gratifying advances in the science itself. Yet there remain conspicuous gaps in our knowledge even of such fundamental questions as where metals come from and how they got to their site of deposition to form orebodies. Thus two such contrasting processes as the orthodox theory of hydrothermal solutions and the hypothesis of lateral secretion (lately resurrected in a new guise invoking long-range diffusion) can both have serious advocates only because of a lack of factual knowledge of the behavior of metals and other substances at moderately high temperatures and pressures, knowledge that could be made available through adequate research.

This is but one example of the kind of background knowledge essential to the development of truly enlightened methods of orefinding but unlikely to be available in time to be useful in replenishing our dwindling ore reserves unless research is intensified beyond the rate of the past half-century.

Mining companies, like other progressive corporations, would undoubtedly sponsor additional research if convinced of its ultimate benefit to the industry but geologists will have to point the way.

As this year is the thirty-fifth in the history of the Society of Economic Geologists and, paradoxically, the fiftieth anniversary of the journal that serves as the Society's Bulletin,[2] it presents an occasion for a brief survey of the progress of the profession during the past half century together with a bit of soul-searching concerning the direction in which it might hope to advance in the future.

From interests chiefly centered on the geological aspects of mining, the profession had broadened its scope to comprise applications of geology to petroleum, groundwater, coal, industrial minerals and engineering problems,

[1] Presidential address before the Society of Economic Geologists, Chicago Meeting, February, 1955. The published version has benefited from the critical reading by F. M. Chace and T. M. Broderick.

[2] Although the Economic Geology Publishing Company and the Society of Economic Geologists have always been separate corporations, the cooperation between them for the last 35 years has been highly satisfactory to both parties.

but with the permission of our colleagues in these fields, I would like to focus attention on its original nucleus, mining geology.

RETROSPECT

To the mining industry, geology unquestionably brings a more useful brand of science than it was able to do fifty or even thirty-five years ago. But if we are correct in saying, as so many of us have, that the finding of ore is as much an art as a science, it seems equally fair to admit that the art of application has advanced more conspicuously than the background of theory. Our maps are more detailed and more faithful to nature, our files of plans and sections are better systematized, and our methods of presenting three-dimensional data are more graphic. Our understanding of the patterns of veins, the three-dimensional aspects of faulting, and the shapes of folds has improved along with the technique of mapping such features. To see the degree of improvement one need only compare today's maps of the Homestake mine or the Broken Hill district with those of fifty or even thirty-five years ago. But it would be hard to apportion credit for this improvement as between better insight and better seeing, for the washing of walls and the retirement of the old-fashioned candle are humble but revealing advances.

In the field of mineralogical investigation, mining geologists have developed a splendid technique for the study of ores under the microscope and have accumulated an abundance of textural data.

In the realm of human relationships the entente between mine operators and geologists is far more cordial. No longer do the miners look upon the geologist as a curious creature from a different and not necessarily superior world, as "underground astrologer" or member of the Guess Department. Thanks partly to a generation of geologists better versed in the everyday problems of mining and partly to a better educated mine staff, the resident geologist is regarded as a human being and a normal part of the mining organization.

Among processes of ore deposition it is only to be expected that an understanding of the supergene enrichment of sulphides, a process that takes place under our eyes and at temperatures and pressures readily simulated in the laboratory, should have yielded to the pressure of inquiry. A concerted attack under Graton's leadership, resulting in the publication of some sixteen papers and followed by the studies by Locke, Blanchard and their associates has achieved a far better understanding of supergene processes than existed in 1900 when the first comprehensive papers on the subject appeared.

But toward an understanding of the more difficultly reproducible processes of primary sulphide deposition, I cannot help feeling that our progress has been less impressive. While the growing volume of descriptions and photomicrographs has given us a vastly better factual knowledge of the mineralogical relations in ores, we are still unable to agree on what the textures mean; at one extreme is the notion that each mineral or stage in the inferred sequence reflects the arrival of a new and differently flavored batch of solution; at the

other extreme is the endeavor to construe the observed textures as rearrangements in response to changing phase-relations following initial crystallization.

Mineralogical relationships as seen on a larger scale have been clarified by the zonal theory of ore deposition, a major concept developed during the last few decades, but I have yet to hear of a deep shaft or drill hole put down on the basis of pure zonal theory. (It is true that development of a deeper productive zone in the Coeur d'Alene Silver Belt has proved successful but this was based on habits of occurrence already well established in the district by methods quite independent of any theory.)

We still are not sure just why ore deposits are zoned. Temperature? Probably. Decreasing solubility? Maybe, but solubility of what in what? We shall not be able to answer the question until we really feel sure where metals come from, how they are transported and what makes them deposit. How much have we learned about this in the past half century?

Status in 1905.—To appreciate what was known and believed fifty years ago, let us imagine that this is the year 1905 and that we are all students of geology. It looks as though we would have some reading assignments coming up because the Geological Survey's publication list for this early year of the century includes promising professional papers on Bingham, Tonopah, Clifton-Morenci and Marysville. The Washington grapevine reports that manuscripts on the Coeur d'Alene and on Georgetown, Colorado are well on the way toward publication.

Each of these volumes has a section entitled "Origin of the Deposits," or words to that effect, in which the author concludes that the ore was deposited by hot solutions derived from a nearby magma. The reader is not asked to take this conclusion for granted. Instead the authors devote several double-columned pages to evidence and argument in support of the idea. And well they may, for although the idea is not new (it was strongly advocated by Stelzner a quarter of a century earlier and in one form or an other by Elie de Beaumont and others long before that) it has only recently gained acceptance in this country. It was but 11 years ago (1894) that Posepny sent to the A. I. M. E. his classic paper opposing lateral secretion and advocating the close relationship of ore deposits to hot springs. Kemp at Columbia is preaching the doctrine of magmatic origin and has an article in the first volume of Economic Geology. Waldemar Lindgren is said to be working on a paper on the relation of ore deposition to physical conditions to be presented next year at the International Geological Congress in Mexico City.

But this vigorous group of young geologists has strong opposition. It was only last year (1904) that Van Hise's weighty Treatise on Metamorphism came from an oversized bindery emphatically elaborating the hitherto orthodox doctrine of lateral secretion and decrying the heretical views of the magmatists. He maintained that ores of the "dominant class" were deposited by solutions of meteoric origin that derived their metals from rocks within the zone of fracture.

There matters stood in 1905.

Status in 1930.—May we tear off several sheets from the calendar and imagine that it is 1930? The hydrothermalists now clearly hold the field,

with the smoke of battle lingering only around those last outposts, the Mississippi Valley and the Michigan coppers. Fenner is shortly to write:

> At the present time there is probably general agreement among geologists that most ore deposits have derived their economically important constituents from magmatic sources (*2*).

True, the professors are still recounting the controversy of lateral secretion vs. hydrothermal origin, but the students in this comfortable era seem a bit bored by it all, though they are willing to indulge the veterans in the diversion of refighting old battles that are otherwise long since forgotten.

Recent Proposals.—Today there is no such ground for complacency. The once-radical hydrothermalists now find themselves on the conservative side under the impact of "modern" views so reminiscent of certain aspects of lateral secretion that one can almost hear the elder geologists in our midst sighing: "This is where we came in" or "plus ça change, plus c'est la même chose."

Objections to the orthodox hydrothermal theory seem to arise partly from the recognition that rocks of igneous aspect can originate through metamorphism. Those who maintain that all igneous rocks, or at least all granitic rocks, originate in this manner find little place in the scheme for ore solutions of magmatic origin. Noting the high mobility of quartz and of some other minerals under conditions of metamorphism and emphasizing as did Sandberger seventy-five years ago that the minerals of veins often reflect the mineralogy of their wall-rocks (many veins in quartzite are filled with quartz; veins in marble are filled with calcite etc.) it is but a short step to derive all the minerals of veins from their wallrocks. Finally, recognizing the low solubility of quartz and the even lower solubility of most sulphides in pure water, they reject moving solutions as a means of transport.

Thus the "neo-lateral secretionists," if they may be so-designated, see the constituents of an ore deposit leaving their original sites in the rocks and diffusing, whether through the medium of static pore solutions, or even through submicroscopic openings without the aid of fluids, to assemble in veins and replacement deposits.

These views stem chiefly from students of metamorphic geology who, with a few notable exceptions, have not devoted long careers primarily to the study of varied ore deposits. The fact that most practicing mining geologists have not, or not yet, rushed to embrace the new views may mean one of two things: The mining geologists' powers of observation and reasoning have been dulled by long indoctrination in mistaken theories, or many of the things they have observed do not lend themselves readily to explanation by long-range diffusion. But there is a third possibility, more charitable both to mining geologists and to the merits of lateral secretion, namely that only recently have the potentialities of long range diffusion received their due recognition.

Is Diffusion Adequate?—In the mobilization of atoms and ions there is as yet no final answer to the question of logistics, that is, whether sparsely distributed metals, even though activated and impelled to march to a vein can

succeed in assembling in it within the allowable limits of time. For despite the vast duration of geologic epochs, the time available for the growth of an ore deposit is by no means unlimited.

The gold deposits of the Sierra Nevada formed after the intrusion of the batholith in the late Jurassic but before the deposition of the Knoxville and Franciscan formations, which are still Jurassic (7). In other districts ore deposition was limited to the interval between two ages of petrologically similar dikes or to the duration of a single spasm of faulting.

So it is all very well to show, as Ramberg does (5), that in 100 million years enough sodium could be transported by diffusion through 100 meters of rock to form a layer 290 meters thick, but if instead the time is taken at 10,000 years the layer is only 2.9 cm thick, a rather less impressive concentration.

The building of metal-bearing veins by this mechanism imposes still further strains on the time-factor. For example, to concentrate the lead from the average rock into a meter-wide vein of 20 percent ore would call for the mobilization of all the lead from a zone some 20 kilometers in width as compared with 100 meters used in the example, and as the concentration of lead in the rock could be but a minute fraction of the 10^{-2} grams per cc assumed in the calculation, the diffusion potential would be infinitesimal in comparison. Finally, the temperature throughout such a band of rock adjoining an epi- or mesothermal vein would be much lower than that assumed for chemical reactions in metamorphism.

But I must leave it to others better versed in thermodynamics to extrapolate our all too meager data into such prodigious extensions of space and time. I wish merely to emphasize that, geologically speaking, ore deposition of ore is a hasty process.

Admittedly, in truly metamorphic terrains there are strong suggestions of a close link between ore deposition and regional metamorphism. The copper and zinc deposits in Paleozoic rocks from southern Quebec to Virginia are in the low to middle grade zone of metamorphism peripheral to the broad belt of gneisses and granitic plutons that lie closer to the seaboard. In Western Australia and in Ontario many of the gold deposits are also in low to middle grade slates and greenstones and although some of them are in or near small intrusive stocks, they are removed by at least a few miles from major exposures of granitic rocks and granitized areas. Thus in the Porcupine district it is not easy to say where regional chloritization of the mafic lavas leaves off and the outer chloritic zones surrounding the orebodies begin. The gold-bearing veins seem to differ in degree (size, closeness of spacing and metal content) rather than in kind from the barren veins of the surrounding region. It is as though the productive areas were local centers where mineralizing activity reaches a maximum. But the high content of water and CO_2 in the regionally chloritized and carbonated lavas suggests, to me at least, that this regional low-grade metamorphism was itself hydrothermal in character.

Be that as it may, the extension of metamorphic theories (especially those theories denying the agency of fluids) to the deposition of ore in regions

that are virtually unmetamorphosed calls for explanation of some commonly observed facts that ore solutions originating at depth can readily account for, once it be granted that such solutions are possible.

One of these facts is the very common occurrence of orebodies in permeable or reactive rocks underneath less permeable or less reactive layers. Leadville is a classic example. While I have never seen any statistics, I feel sure that most experienced geologists would testify that primary ore is much more commonly found below impermeable beds than above them. It looks as if something must have been moving upward and not downward or sidewise.

A second feature that ore solutions can readily account for is the occurrence of pipelike orebodies (and the term here applies both to steeply and gently inclined pipes). One of the most convincing examples is Gilman, Colorado, as described by Tweto and Lovering (8). Here the sulphides have been deposited in tubular cavities that were dissolved out of the limestone by a fluid solvent, as attested by bedding and even ripple marks in the dolomite sand that occupies the cavities. In many other districts there are similar pipes and they are hard to explain as groundwater caves because in repeated instances the lower end is not an old cave-mouth or even an aquifer but an intrusive body. Pipes in granite like those in eastern Australia, are even more difficult to explain as vadose caves. This looks suspiciously like the work of ascending solvents. And in district after district where groups of pipes and mantos form part of an ore cluster, the metals are arranged zonally, and the zoning bears a much closer geometrical relationship to postulated channels of solution-flow than to any geotherms that could be attributed to simple conduction of heat from an intrusive or other source.

Perhaps the most definite testimony to the genesis of ore deposition is to be sought in the facts of wallrock alteration as exemplified by the studies of Lovering, Schwartz, Kerr and many others. Sales and Meyer's work at Butte which is rapidly becoming a classic example sees the altered rock as a zone of two-way diffusion and it is not a great step from this to regard it as a reaction zone in which the adjoining quartz monzonite is striving to reach equilibrium with the material in the vein-channel. Here, although there seems no reason to question the effectiveness of diffusion, it is not diffusion of material from cubic kilometers of surrounding rock into the vein and altered zone but rather an exchange affecting only the altered zone itself. Clearly, here the diffusion potential is set up by a supply of material in the vein channel that is out of equilibrium chemically and thermally with the adjoining wallrock. Granted that the altered zone may have supplied some of the silica for the vein it is not wide enough, at least in the veins of the central zone, to supply it all (4) and certainly not wide enough to supply the metals and the sulphur. Nor is it evident how lost components like CaO and MgO were disposed of unless they were carried off in solution to deposit as carbonate gangue or to emerge in springs at the surface. That the unquestioned results of hydrothermal alteration, to be seen around hot springs, are so similar to the altered zones of veins can hardly be a coincidence and in at least one instance (Sulphur Bank, California) a hot spring deposit a few feet below the present surface has been mined as an orebody.

Finally, the common association of ore deposits with intrusive bodies and especially with apically truncated stocks, as cogently emphasized by Butler, is so well recognized that even the most skeptical give credit to the magma as a source of heat. To look elsewhere for the source of metals seems like ignoring Occam's razor. It appears even more far-fetched to seek an obscure source for the millions of tons of iron sulphide at Cerro de Pasco when a volcanic neck is near at hand, and so for the ores of Braden, Llallagua and Oruro. The agent and its product seem equally closely linked in any one of a thousand contact metamorphic ore deposits, many of which grade into veins and mantos.

This by no means exhausts the list of observations that any theory of ore deposition must account for. Other evidence favoring hydrothermal origin as well as evidence opposing it, to be found in the now almost forgotten literature of half a century ago will repay perusal by anyone who would derive ore from sparse distribution in surrounding wallrock. Even though it may not change his views, it will at least prepare him for objections that he is likely to meet.

But these allusions to evidence in support of orthodox concepts are intended merely as a caution against too ready acceptance of a plausible hypothesis on the basis of mere novelty or fashionableness. They are in no sense intended as a disparagement of new concepts as such. Certainly any ideas that will help toward a clearer understanding of ore deposition are more than welcome and the fact that one concept happens to be generally accepted is no reason to excuse it from bearing its full share of the burden of proof. As it is only by presenting evidence for and against any idea, whether old or new, that we can get closer to the truth, it follows that those who support either the affirmative or negative side of a debate need offer no apology.

NEED FOR RESEARCH

But debate in itself, stimulating and necessary as it is, will not bring the ultimate answer. The very circumstance that each of two such contrasting theories can have its serious advocates shows how sorely we are in need of facts. Unfortunately those of us who are partial to hydrothermal solutions are obliged to accept them more or less as an article of faith, for we are, so far, quite unable to show that such solutions (at reasonable concentration) are even chemically possible. This, in fact, is the weakest link of the hydrothermal chain of reasoning: the low solubility of sulphides in water, especially the commonest sulphide of all, the sulphide of iron.

This weakness was not ignored by the hydrothermalists of the Lindgren school; it was a problem that caused them much concern and they endeavored to meet it by resorting to solutions of extremely dilute concentration in metals. But even Lindgren himself did not seem quite happy about this, for in his later years he turned to colloidal solutions as more efficient carriers of metals. However, colloidal solutions after a brief vogue, seemed to lose their appeal as a cure-all; further investigation of colloidal phenomena did not seem to support them, at least for high temperatures. The opposite extreme, intro-

duction of sulphides as dry (or even wet) melts failed likewise to achieve general acceptance, partly because the melting points of sulphides as known from studies of mattes are above those which mineral assemblages of deposits in the hydrothermal group would seem to permit, and partly because the chief evidence in favor of "ore magmas," viz. unsupported inclusions, faded with better recognition of the results of replacement. Transportation in a dense vapor phase without the aid of a solvent meets even more difficult problems of temperature.

Thus ore solutionists are still, like the alchemists of old, in search of a universal solvent. Most metals are soluble as sulphate but what about barium, so common in a variety of veins? Many metals are soluble as chloride, but what about silver? And can chlorides remain in solution in the presence of sulphur? Even the solubility of chloride complexes is vanishingly small.

But to assert that no plausible solution can exist would seem presumptuous so long as our knowledge is limited to test-tube chemistry at low pressures. We do not even have a phase diagram for the iron-sulphur-water system up to a few hundred degrees, not to mention a four component system including CO_2 or a five component system including an alkali. At best it will be a long time before any such five component system can be worked out. The reason why we have hardly even made a start on it lies, of course, in experimental difficulties, but more serious difficulties than this have been overcome in the past. Until these commonest of systems have been explored, at least in a preliminary way, it seems just as unsafe to deny that iron and sulphur can travel in the same solution as to assert that they can. And so for other metals. So while some of us are of the opinion that geological evidence is all in favor of solubility this must still be an opinion and if we are wrong, the sooner we find out the sooner we can get on the right track.

But I have harped on this particular problem, the manner in which metals may have become concentrated, merely because it is so fundamental and not because it is the only, or even perhaps the most practical problem that awaits solution. Many others, some of them with more immediate promise of productivity, have been listed by research committees of the Society of Economic Geologists and other organizations (1, 6). But because many of these are chemical problems it may not be amiss to insist that useful answers will be long delayed if search is confined to the laboratory alone. The work of the chemist and physicist will be of the ivory tower variety unless it is tied closely to observations that can be made in the field and underground. Thus, although it might be intellectually satisfying to investigate all possible chemical relationships before attempting to apply any of them to the problems of ore deposition, such a methodical approach would be comparable to attempting to solve a murder mystery by first studying the characters and habits of all known criminals. The detective who seeks earlier results will prefer to visit the scene of the crime and allow the fingerprints he finds there to direct him to the next step in the inquiry.

Meanwhile time is running out and so are ore reserves. In some of the world's great districts the depth to which drill holes of reasonable length can

probe, and known geophysical methods can reach, have already been pretty well tested. Yet our strictly geological methods of ore finding are still essentially empirical: Find out how the ore occurs and look for places where the same conditions are repeated. But because conditions that seem favorable in one district are not always favorable in another we still dare not venture far away from the ore itself or from some direct signs of it such as outcrops or geochemical or geophysical anomalies. When shall we learn to make confident predictions on any basis other than simple structural relations? For example, if ore deposits come from a magma, how far will they be from what kind of magma? Admittedly the answer to this naive question involves many factors but what are the factors and how shall we learn to phrase them in arabic numerals? We still need to develop an unexceptionable theory of ore deposition and it will have to be based on a long program of research.

PROSPECT

Who is going to do the research? The universities, the government agencies and several of the mining companies have been doing excellent research for years but it has not proved to be enough. With the increasingly elaborate and expensive equipment required for modern methods of investigation, university funds are mere white chips in the game. Government-sponsored research can point the way but must we say along with so many varied political factions today: "Let the government do it"? It is the mining industry that will benefit from more effective methods of ore finding and it is the mining industry that will die of anemia if its life-blood, the ore-supply, is allowed to run dry. If research is not to be left wholly to the government departments and the private foundations, it is the mining companies that must sustain it, whether individually or cooperatively.

One reason to hope that mining companies will continue and intensify their programs of research is that an increasing number of mining executives are coming from the ranks of technical men who appreciate both the possibilities and the limitations of geological science. They realize that even an important advance in fundamental geological theory may not point directly to new orebodies next year but if it is a sound concept it will lead to the sharper thinking needed to find ore that will be required in another decade or two.

But even the best informed executives have their fellow-directors' and ultimately their stockholders' views to consider and the unfortunate fact is that the otherwise enlightened public is woefully unacquainted with either the possibilities or the limitations of geology as a tool in ore-search.

For this we geologists are largely to blame. Our own conversation is, like my offering tonight, centered around controversial subjects because it is such things that we find interesting and stimulating. As a result the hardrock mining man smiles either tolerantly or sardonically and says: "No two geologists ever agree about anything." We can agree at least that his oft-heard pronouncement is inaccurate.

But we have no need to restrict our public utterances to forensics or even to the alternative of hum-drum description. In spite of its all too evident limitations, geology has made repeated and highly important contributions to the discovery of ore, yet even geologists themselves may be hard-pressed to cite off-hand very many discoveries made by strictly geological methods. One reason for this may be that the part played by geology is not always easy to assess. Who deserves the credit for opening an extension of the Rand, a Grace Mine, a Cerro Bolivar or a new West Indian bauxite deposit, the geologist who recommended the work, the executive who approved it, the financier who provided the funds or the driller who bored the holes? Each deserves his share but in the general exchange of felicitations, geology sometimes loses out. The staff geologist who is in a position to know just what part geology played is often too inarticulate either because of his becoming but regrettable modesty or of restrictions imposed on discussion and publication, which ought in all reason to be lifted after they have served their original purpose. Examples of discoveries by geological methods are multiplying so rapidly that in order to keep up to date, we need more papers like Ira Joralemon's (3) of eight years ago in which he listed some thirty-seven major discoveries in the preceding decade and showed that in at least twenty-seven of them geology played a leading part. But before such examples can be compiled, somebody has to tell about them.

Role of Geophysics.—This emphasis on fundamental geology is in no sense intended to minimize the role of geophysical methods in the program of orefinding. Whether geology is a subdivision of geophysics as some of the literature emanating from Washington might imply, or whether geophysics is a branch of geology as others of us would like to maintain, there is not and ought not to be any barrier between the two aspects of a single science. Geologists, I believe, can take heart from the progress that geophysics has made in the past thirty-five years. Once dimly viewed with that mixture of awe and suspicion now reserved for Henry Gross and his dousing rod, geophysical methods are today considered indispensable in the search for those types of ore deposits to which they are adapted. This degree of acceptance, although not achieved without a discernible modicum of publicity, has resulted primarily from constant research and improvement, financed by both public and private funds. But affirming the unity of two branches of the science ought not to be carried to the extent of riding either on the successes of geophysical exploration or on the promise of geochemical and geobotanical methods. The understanding of processes of ore deposition must advance equally rapidly if it is to carry its needed share in the partnership.

CONCLUSION

I have intimated only one or two of the many lines of research that mining geology needs to pursue if it is to contribute in full measure to the discovery of the world's needed ore reserves. Research is a magic word today and corporations are willing and even anxious to underwrite it if they can be

convinced that it is a prudent investment. It is up to geologists to show them that it is.

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SULPHIDE MINERALIZATION IN THE SKELLEFTE DISTRICT, NORTHERN SWEDEN, AND ITS RELATION TO REGIONAL GRANITIZATION

SVEN GAVELIN

ABSTRACT

The geology and ores of the Skellefte District in Northern Sweden are described and the relations to regional Svecofennian geology are discussed. Most of the deposits consist of compact pyrite ore with chalcopyrite, sphalerite, galena as other essential ore minerals. Arsenopyrite and gold in places are significant constituents, as for example in Boliden. The ore bodies are generally surrounded by sericitized or chloritized rocks but also more high-grade secondary minerals may occur. During recent years the total output of ore from the district has exceeded 1,000,000 tons annually.

The mineralization is connected with granites that are assumed to have originated by palingenesis and granitization, at least in part of sediments, where graphite-bearing pelites play a significant role. Therefore, it seems possible that also the metals of the ore deposits were derived originally from these sediments.

INTRODUCTION

As a result of geological investigations and prospecting since 1918 the Skellefte District in Northern Sweden now appears as the most prominent sulphide ore district of the Pre-Caledonian areas in Fennoscandia. Several descriptions of individual ore bodies and ore districts in this area have been published but the only recent survey of the entire ore province was presented in Swedish in 1946 by the present author and the chief geologist of the Boliden Mining Company, Dr. E. Grip (13). Recently a map of the rocks of the Västerbotten County has been published, the northern-most portion of which comprises the Skellefte District, and in addition a description to that map has been prepared by the present author (14). This work is to a great extent a compilation of geological research performed by several geologists during the period 1918–1945. The description of the ore deposits of the Skellefte District was performed in cooperation with Dr. Grip and the results were summarized in the above-mentioned publication of Gavelin-Grip 1946. As the description to the new map is in Swedish (with just a brief summary in English) and as it is now possible to view the genetic problems of the ores in the light of the regional geology of the North-Swedish areas, some significant results will here be summarized. In addition, the bearing of these results to certain problems concerning ore formation in the Fennoscandian Pre-Caledonian areas as a whole will be considered.

REVIEW OF GEOLOGY AND ORE DEPOSITS OF PRE-CALEDONIAN AREAS OF FENNOSCANDIA

Figure 1 shows some of the main geologic features of Fennoscandia. The main portion of the area is built up of Precambrian rocks but the northwestern Sweden and the chief parts of Norway are occupied by the Caledonian mountain range. Rocks of Cambro-Silurian and younger age have a fairly limited extension outside the Caledonian belt.

In the highly varying assemblage of Pre-Caledonian rocks granites and gneisses are prevalent. In addition are also other intrusives and supercrustal rocks that have escaped metamorphism to such an extent that their original character can be defined. On the basis of the regional distribution of the various rocks and of their mutual age relations a general conception of the Precambrian evolution in Fennoscandia has been accepted by most Fennoscandian geologists. According to this conception the present surface presents the roots of three different orogenic belts and at least three orogenic cycles can be discerned (given in the order from older to younger cycles) : 1. The Svionian or Svecofennian cycle; 2. The Gothian cycle; 3. The Karelian cycle (for a more thorough presentation of this division, see Magnusson, 28). Subsequent to the Karelian rocks there occurs a series of unfolded rocks comprising plutonites, volcanites and sediments, which are known as Sub-Jotnian and Jotnian (Algonk).

Non-gneissic supercrustal Svecofennian rocks form a belt that extends in an east-west direction from the eastern portion of Central Sweden to southeastern Finland. Most of the Svecofennian supercrustal rocks are transformed into gneisses, however. These are delimited in the west and the south-west by granites and gneisses of the Gothian Cycle, which form a belt with a marked north-south extension (Fig. 1). The same kinds of rocks also make most of the Pre-Caledonian, south-western portion of Norway. Non-gneissic Gothian sediments and volcanites also occur.

The Svecofennian gneisses are in eastern Finland delimited by the Karelian belt, there striking NNW. The low-metamorphic, typical Karelian rocks form a characteristic series of conglomerates, quartzites, limestones or dolomites, and slates, but at some places these rocks have been intruded by granites and metamorphosed to gneisses, which are not always possible to distinguish from the Svecofennian gneisses. In Figure 1 the main quartzite belts have been denoted in order to demonstrate the general pattern of the Karelian belt. The heavy broken line denotes an approximate western boundary of indisputable Karelian structures. East of the low-metamorphic Karelian belt more ancient rocks, possibly of Svecofennian age, once more appear, but they will not be considered here since they have no bearing on the actual problems concerning ore genesis.

The gneisses north of the Central Swedish Svecofennian belt extend to the Skellefte District, where again low-metamorphic volcanites and sediments appear. Further to the north both Svecofennian and Karelian rocks occur, but it is not possible to denote them separately on the generalized map of Figure 1.

FIG. 1. Survey of some principal geologic features of Fennoscandia and of its ore deposits. (The Caledonian deposits have also been indicated although they are not discussed in this paper.) Heavy continuous lines denote boundaries between main geologic units: The Caledonian belt (C), the Algonkian (Sub-

The presentation in Figure 1 is only intended to give an idea of the main orogenic belts and does not mean to represent a strict delimitation of rocks of various ages. So, for instance, to a certain extent Archaean rocks appear even in the Caledonian areas, and most probably rocks of originally Svecofennian age, occur in the Gothian and Karelian belts.

In all of the three Precambrian orogenic cycles late- or, in part, post-kinematic granites occur, which commonly are intimately connected with the formation of veined gneisses and migmatites. Such granites, at least in part of a distinctly palingenic origin, are widely distributed and have been denoted on Figure 1, irrespectively of their relative ages. The areas comprising non-gneissic supercrustal rocks, which have been denoted on the map, also include early-orogenic granites, which in most cases make a dominant part of the entire granite-supercrustal rock mass.

Figure 1 also shows the distribution of the principle ore deposits. Only deposits of magnitude, which are or have been of commercial importance have been included. In the Pre-Caledonian areas of Sweden three main ore districts can be discerned: the Central Swedish ore district or Bergslagen with both sulphide ores and iron ores, the Skellefte District in Northern Sweden with exclusively sulphide ores and the northernmost (Lappland) iron ore district with almost exclusively iron ores.

The Central Swedish ore district is confined to the Svecofennian belt and from Figure 1 it is clear that also the small iron ore deposits and the sulphide ores in south-western Finland are situated in the Finnish portion of this belt. Consequently they can be considered to represent the same ore province. The ores of the Skellefte District are also situated in rocks that have been assigned Svecofennian age and a recently discovered sulphide deposit due east of the Skellefte District in Finland can be considered as the continuation of this ore province on the Finnish side of the Gulf of Bothnia. The most important of the deposits in the North-Swedish iron ore district, the phosphorous iron ores (Kiruna, Gellivara etc.), are also assumed to be of Svecofennian age, whereas some other types of iron ore and the sulphide mineralization are connected with Karelian rocks. In the form of Karelian iron ores the ore district continues in northern Finland (Fig. 1). The principal Karelian belt in eastern Finland contains the most important copper ore of Fennoscandia, Outukumpu, and some small pyrite and one molybdenite deposit.

Jotnian and Jotnian) areas, the Gothian belt (G), and the Svecofennian belt (S). The heavy broken line represent an approximate boundary for the Karelian belt in eastern Finland. The area contained within the rectangle on this map is given on a larger scale in Figure 2.

1. Cambrian and younger rocks outside the Caledonian belt. 2. Rocks of the Caledonian Mountain Range. 3. Jotnian—Sub-Jotnian rocks and post-Karelian granites not connected with migmatization. 4. Karelian quartzite belts. 5. Granulites of northern Finland. 6. Gneiss formations. 7. Supercrustal formations with synkinematic granites. 8. Late- and post-kinematic granites, at least in part of a palingenic origin. 9. Iron ore (other than titaniferous ores). 10. Titaniferous iron ore. 11. Sulphide ore (other than Ni- and Mo-ores). 12. Nickel ore. 13. Molybdenite ore. 14. Tungsten ore.

From the above it may be seen that ore deposits of salient commercial interest are connected with both Svecofennian and Karelian rocks. In the Gothian belt ore deposits are rare. Two of the iron ore deposits denoted within this area on Figure 1 are titaniferous and associated with basic intrusive rocks, a type of ore which is of little interest to the problems to be discussed, and which is represented in rocks of highly varying systems in Fennoscandia (even in the Caledonian mountains). For the iron ore on the Norwegian south-east coast an original Svecofennian age has been suggested; the other iron deposits in this part of Norway are small. Of sulphide ores only a molybdenite deposit (Knaben) is worth mentioning. Indications of tungsten mineralization, which may turn out to be of economic significance, have recently been discovered in Norway. This is of interest since also in Sweden, not far from the border towards the Svecofennian belt, a wolframite deposit has been mined. From the above it can be stated, however, that the types of ore deposits characteristic of the Svecofennian and Karelian areas are almost entirely lacking in the Gothian belt.

GEOLOGY OF THE SKELLEFTE DISTRICT

The Skellefte District is separated from the southern Svecofennian ore-bearing belt by a wide area of gneisses and palingenic granites (Fig. 1), and is characterized by more low-metamorphic supercrustal rocks. In certain areas these have well preserved original structural features. Both volcanites and sediments occur. Three main divisions can be distinguished: One lowest, mainly a volcanic rock sequence with meta-ryolitic, meta-dacitic, meta-andesitic, and meta-basaltic lavas and tuffs; one intermediate, mainly a sedimentary division, where lutitic sediments of the graywacke series (according to the definition of Pettijohn, 32) are prevalent, and where graphite-bearing phyllites or schists play an important role; and one upper division of volcanites, mainly lavas, of varying chemical compositions. The graphite-bearing sediments generally contain more or less pyrrhotite or pyrite.

The supercrustal rocks have been folded and intruded by two generations of plutonites. The first group has generally a granodioritic composition and generally forms masses concordant with the supercrustal rocks. True pegmatites connected with these plutonites are almost entirely lacking. The second group of plutonites consists principally of potash-soda granites. Their crystallization is post-, or in part, late-kinematic. They are associated with abundant pegmatites of the same kind as make an integral part of the veined gneisses, and these granites are therefore assumed to be intimately connected with the origin of the gneisses immediately south of the Skellefte District proper. There is also a conspicuous spatial connection between the distribution of the late-kinematic granites and the gneisses.

Field conditions indicate that the gneisses have been derived almost exclusively from the principally lutitic graywacke sediments. The areal distribution of the various rocks in the Skellefte District and its environs shows that these sediments must have had a very wide extension south of the Skellefte District proper, but that they wedged out towards the north and north-west.

The first stage of orogenesis was caused by pressure acting from SSW towards NNE, which formed a set of persistent synclinal and anticlinal belts in the Skellefte District proper (composed of both volcanics and sediments). In this stage of orogenesis the first series of plutonites were emplaced. In the second stage of orogenesis these granites acted as resistant blocks, deflected the initial direction of pressure and caused a distortion of the previous tectonic pattern, Grip (17a).

In Figure 2 some of the principal structural features of the Skellefte District are summarized. The arrows show the deflection of the pressure and the distortion of anticlinal and synclinal belts, assumed to have had originally a more consistant WNW-strike. The younger granites are emplaced in the final stage of this second orogenic phase. In Figure 2 in the central Skellefte District are four protrusions (denoted by P on the map) from a more continuous area of merely gneisses and granites in the south. The extension of these protrusions to the north seems at least in part be dependent on the absence of resistant blocks of older granite. In part they cut the older structures, in part they form masses spread out "over" the folded supercrustal series. The deformation of the older structures shows a certain degree of conformity with the protrusions and in front of the second protrusion from the east an overthrust or upthrust has been indicated at the mapping of the area (6, p. 23).

Field evidence from the vast granite and gneiss areas south of the Skellefte District has lead the author to assume the gneisses and granites to be both formed by a high-grade metamorphism during the second orogenic phase. The granitization lead to mobilization of granitic masses, which in the final stage of orogenesis emerged and were pushed towards the north, at some places forming protrusions of the kind mentioned above. This interpretation is supported also by the development of regional metamorphism.

Metamorphism that can be connected with the emplacement of the older granites is very faint and has only local extension. The regional metamorphism, on the other hand, is in a certain respect related to the younger granites. This does not mean that the isograde in all cases are conformable with the various granite boundaries, however. In Figure 2 a boundary line between areas characterized by biotite, and areas characterized by chlorite + sericite in acid volcanites is drawn (this is the isograde for the transformation sericite + chlorite → biotite). If one ignores the granite protrusions already discussed, there is fairly good conformity between the granite-gneiss front and the course of this isograde (Fig. 2). In addition a continuous increasing metamorphism is indicated by textures and mineral composition of the supercrustal rocks from the biotite isograde towards the gneiss front. It is significant that the granite protrusions to a certain degree cut across the isograde and also that the most conspicuous intrusive phenomena are connected with these very protrusions, which are assumed to represent the most intensely mobilized portions of the granitized masses.

After the orogenic evolution described above, there followed a long period of denudation that laid bare even the granites. On this eroded surface new sediments and volcanics were deposited, which are assumed to be of Karelian age. These supercrustal rocks occupy only fairly small areas, but

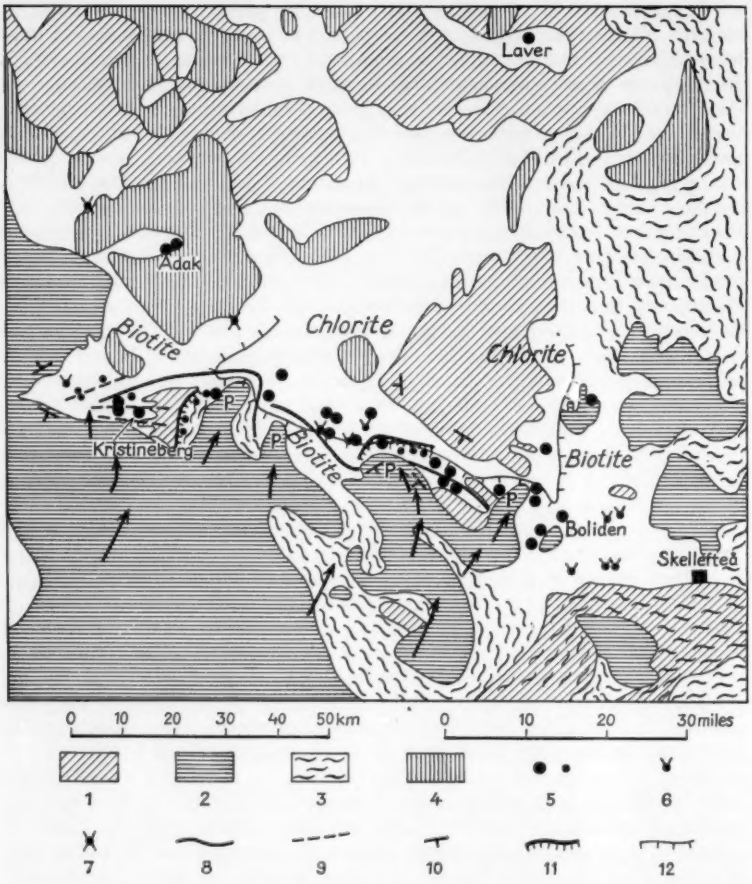

FIG. 2. Ore deposits and some principal geologic and structural features of the Skellefte District and adjacent areas. The position of the area is shown in Figure 1.

1. Synkinematic Svecofennian granite. 2. Late- or post-kinematic Svecofennian granite. 3. Veined gneisses and migmatites. 4. Late or post-kinematic Karelian granite. 5. Sulphide ore deposits (other than Ni-ores). Small circles also include a group called "small sulphide concentrations of pyrite and pyrrhotite in schists and gneisses" in the previous publications. 6. Quartz veins with arsenopyrite. 7. Nickel ore. 8. Persistent belts of graphite-phyllites, sometimes synclinal belts. 9. Anticlinal belts. 10. Strike and dip of granite contacts. 11. Thrust or fault lines. 12. Isograde referring to the transition sericite + chlorite → biotite in acid volcanic rocks.

they were intruded by granites that have a wide areal extension, especially north of the Skellefte District proper.

MINERALIZATION IN THE SKELLEFTE DISTRICT

Mineralogical and Structural Features.—Figure 2 presents various types of mineralization occurring in the Skellefte District and the distribution of the ore deposits and prospects. The two types "quartz veins with arsenopyrite" and "small sulphide concentrations of pyrite and pyrrhotite in schists and gneisses" have never attained dimensions and grades such as to make them minable on a commercial scale, but they have been indicated since they have a bearing on ore genesis on the whole. The ores of commercial significance are preponderatingly massive pyrite masses with various amounts of chalcopyrite, sphalerite and, to a less degree, galena. A certain fractionation of copper, zinc and lead in separate copper ore and zinc-lead ore portions is generally obvious. Mineralization has been accompanied by alteration of the wall rocks: where silicious the wall rocks have been transformed into sericite-schists or chlorite-schists, at places also with almandite, biotite, cordierite, andalusite, staurolite, cummintonite; where originally calcareous the wall rocks were changed into lime-silicates (diopside, actinolite-hornblende, andradite, epidote). In most cases the metasomatically altered rocks form aureoles around the ore bodies, but they may also have a more regional extension (e.g. in the Kristineberg Area, (4), approximately 100 sq km and in the Adak Area, T (9), 5 sq km). This kind of ore is well known in various ore districts all over the world and on several previous occasions the great similarity to certain mining districts in the Precambrian Shield of Canada has been stressed (e.g. Noranda, Mandy Mine, Flin Flon). Further, some pyritic deposits in the western United States might be mentioned in this connection, for instance the ores of Shasta County, California (24).

Common accessory constituents of the pyritic ores are pyrrhotite, arsenopyrite and, mainly in connection with galena, composite antimony minerals (tetrahedrite, bournonite, jamesonite, boulangerite etc.). Arsenopyrite may occur as practically pure, dense lumps or as lenses—a type of ore specific of the Skellefte District. This type is particularly well developed in the Boliden deposit, the most famous of the Skellefte ores, but has been found also in several other deposits. Arsenopyrite may also occur as scattered crystals in complex sulphide masses.

Gold and silver are commonly valuable by-products in the mining industry and may in some cases (e.g. at Boliden) represent chief constituents. Gold is commonly concentrated in dense arsenopyrite ore or is associated with sulphominerals (Boliden). Silver is mainly associated with ore portions concentrated in lead and antimony minerals.

Massive ore bodies are commonly surrounded by areas where sulphides occur as breccias or impregnations in the altered wall rocks. If chalcopyrite, gold or sphalerite are abundant, such areas may constitute "commercial ore." Copper ore of this kind without any connection with large massive ore lenses is mined in the Adak Area (9) and was mined in Laver (30, 4).

The percentage of metals present is variable. Some approximate average

contents of chief constituents in ore mined, or from areas prepared for mining, are: Pyritic ores 28–40% S, 0–2.5% Cu, 0–10% Zn, 0–2% Pb, 20–300 gr/ton Ag. The gold values are in most cases low, 0.5–2 or 3 gr/ton; in Boliden however the average exceeds 10 gr/ton (variations in various types of ore selectively mined in 1949 are 8–24 gr/ton). The dissemination and breccia ores of the Adak Area now mined contain 2–4% Cu.

Some additional constituents, which are not now extracted from the ores but which are of a geochemical interest, will also be considered. The distribution of tungsten and molybdenum has been considered by Grip (20). Scheelite has been found as scattered crystals in several deposits—in the ores, in altered wall rocks and in quartz dikes adjacent to ore bodies. In 12 of 17 deposits examined by Grip scheelite was traced. The highest percentages were found in a pyrrhotite lens in Boliden where one section of a drill hole of 4.5 m was found to contain 2.7% WO_3. Molybdenite is rare in the ores but has been observed at some localities in quartz or quartz-tourmaline veins connected with sulphide ore. It then seems to be associated with the copper mineralization of the area. In addition, molybdenite has been found in pegmatites associated with the palingenic granites.

Native bismuth has been observed as very small inclusions in galena or in sulphominerals from several deposits. More considerable concentrations of bismuth have been established in Boliden, where bismuth-tellurides and bismuthite occur in quartz-tourmaline veins. Exactly the same type has been found in one little ore prospect, Mångfallberget (21), 2 km north of Boliden.

Tin is rarely present in the form of stannite, which has been observed in some zinc and copper ores. Spectrochemically it was demonstrated to occur as "trace element" in other sulphides.

Cobalt and nickel minerals have been observed in a few localities. In Boliden cobaltite and some additional cobalt and nickel minerals were identified by Ödman (29). The highest contents of Co were recorded in certain types of dense arsenopyrite ore, where the percentage may attain 2.5% Co. A peculiar kind of cobalt-nickel mineralization on a very small scale has been described from the Adak Area (8) and from Laver (31), viz. calcite veins with Co-Ni-arsenides and silver.

Two small ore deposits of a type quite different from those described above, and which can be characterized as nickel ores, have been encountered within the area. One of them, Lainijaur, was mined during the last world war. The principle ore is a pyrrhotite mass with some pentlandite and chalcopyrite. It is associated with gabbro, and is therefore a quite normal type of nickel ore connected with basic intrusive rocks. Lainijaur is particularly interesting, however, as the pyrrhotite-pentlandite ore is penetrated by small veinlets containing nickel-cobalt arsenides and, in addition, scheelite and molybdenite (17)!

The distribution of Co and Ni in the principal sulphide minerals of the Skellefte District was examined by Gavelin and Gabrielsson (12). The variations are considerable but an accumulation of values in the percentage classes $< 0.001\%$ and 0.01–0.09% Co was established for both pyrite and

pyrrhotite. The corresponding Ni-values are lower, generally $< 0.009\%$. Chalcopyrite was lower than pyrite and pyrrhotite in both Co and Ni, whereas arsenopyrite shows a marked tendency to concentrate these elements. Arsenopyrites with up to 3% Co were analysed, but the values accumulate in the percentage groups 0.1–0.9% Co and 0.01–0.09% Ni.

Minerals where selenium and tellurium form essential constituents have until now been identified only from a few deposits. The occurrence of Bi-tellurides from Boliden and Mångfallberget has already been mentioned. From a similar mineral association at Boliden Ödman (21) described two sulphominerals, which because of their significant content of selenium were called "selenocosalite" and "selenokobellite." A mineral assemblage with tellurides of gold, silver and lead has recently been described as associated with one of the ores in the Adak group (11). This mineralization seems to have a very small extension, however.

The distribution of selenium in the principle sulphides of the ores was examined by Bergenfelt (2). Highly varying values were obtained even in different samples of the same mineral and from the same deposit. On an average the succession galena-chalcopyrite-sphalerite-pyrite indicates a decreasing content of selenium. In pure sulphide minerals values from $< 0.001\%$ to 0.14% Se were obtained.

The distribution of mercury has been examined by Grip (18). In most of the ores the percentages are very low (order of magnitude 10^{-3} to $10^{-4}\%$) but at Boliden and one adjacent deposit higher values were also found. The highest percentages recorded were in gold from the Boliden deposit (up to 3.5% Hg) but of the sulphides, sphalerite is the chief carrier of mercury. In the deposits belonging to the Boliden group sphalerite may contain 0.1–0.2% Hg.

The size and shape of the individual ore bodies presented in Figure 2 vary a great deal. There are deposits with large outcropping areas, e.g. Rackejaur 20,000 sq m, the Kristineberg group 16,000 sq m, Boliden 12,000 sq m, but higher grade ores with only a few hundred sq m of outcropping area have also been mined. In the last years approximately one million tons a year have been mined from the total Skellefte District.

The deposition of the sulphides and the shape of the ore bodies has been controlled mainly by structural features. Many of the deposits are situated in the volcanic rocks (with inliers of sediments) not far below the boundary of graphite-phyllite or graphite-schists. As is well-known from so many other ore districts over the world, anticlinal structures were favorable for ore deposition. The pelitic sediments have a very low folding competence as compared with the adjoining volcanites, which makes the border zone between these rocks a region of discontinuity with regard to deformation, and such regions are therefore apt to give rise to fracturing and openings, which can serve as channelways for the ore-bearing fluids. In addition, the graphite-bearing phyllites and schists seem to have been more impervious and have effected "damming" and accumulation of the fluids. Since the structural pattern may be highly different in various portions of the Skellefte District the ultimate cause of the deposition of the sulphides may vary from one ore

district to another and these circumstances also influence the shapes of the individual ore bodies (7, 19).

Relation Between Mineralization and Granites.—The distribution of the ore deposits as shown in Figure 2 gives no direct indication of a spatial relation to either of the two granite groups denoted on the map. The majority of the deposits are found to have originated after the emplacement of the older granites but prior to the late-kinematic granites. Several facts indicate a more close connection between sulphide mineralization and the latter group, however:

1. The alteration of wall rocks connected with the mineralization affects minerals formed by the regional metamorphism, which in turn was shown to be associated with the formation of gneisses and late-orogenic granites. 2. In the Malånäs District the mineral facies of gangue minerals in the sulphide ores are related to the grade of regional metamorphism in the surrounding rocks, not affected by sulphide mineralization. 3. The deposition of the sulphides were commonly regulated by structures formed at the last orogenic phase. 4. Copper-ore mineralization on a small scale, directly connected with pegmatites of the late granites has been observed. 5. Quartz veins with arsenopyrite, in places gold-bearing, display a zonal arrangement in the field, which connect them with the same kind of pegmatites.

On the other hand some of the ores in the north-western portions of the area (Adak, Laver, the Ni-ores) are connected with the emplacement of plutonic rocks of Karelian age and represent, therefore, a much late epoch of mineralization.

Source of the Ore Minerals.—With the assumption of a genetic association between mineralization and granites, which have developed by granitization of sediments, the question concerning the source of the metals in the ore deposits can be considered in various ways. If granitization is presumed to have been caused by "juvenile" emanations from greater depths, metals may have been supplied by these emanations. If, on the other hand, granitization was a process of transformation and migration within a pre-existing crust, the metals *must* also have been derived from the same crust. If one or other of these two processes has been of decisive importance, it is obvious that an eventual content of metals in the granitized pre-transformation rocks must be considered a possible source of the ore substances.

As was mentioned on a previous page, the Svecofennian sedimentary rock sequence in the Skellefte District contains large amounts of graphite-schists with sulphide dissemination. They surely represent originally bituminous sediments and it is well known that sediments of this kind also contain a significant amount of sulphides due to exogenic concentration. The small and irregular concentrations of sulphides in high-metamorphic schists and gneisses in the Skellefte District (Fig. 2) most probably represent concentrations of the original sulphide content of the sediments. We may then ask, if the sulphides in the principal ore deposits may have been derived from the sediments and have migrated as a consequence of high-grade metamorphism?

This interpretation has been considered a plausible working hypothesis by both Grip and the present author ever since the palingenic origin of the

late granites of the Skellefte District was established. Such ideas are not new and have been applied tentatively to ore districts both in Fennoscandia and elsewhere. On the basis of investigations in Central Sweden N. H. Magnusson assumed that sulphides of copper, zinc and lead were driven out from the gneiss masses in the central Swedish Svecofennian areas and concentrated in more low-metamorphic areas.[1] Mineralization according to similar principles have further been advanced by Backlund (1), Locke (26), Sullivan (34), Guimaraes (22) and others. A very interesting report has been published by Clar and Friedrich (3) concerning the relations between metallization, metamorphism and magmatism in the European Alps, the results of which were discussed in Mainz in the German Geological Society (Deutsche Geologische Vereinigung) in 1952, where magmatism and metallization were a subject of the meeting. (A survey of the Skellefte District was presented at the same occasion by the present author). All the authors cited above stress the possibility of metallization as a result of concentration processes connected with granitization. Another view is taken by Schneiderhöhn (33) who recognizes a polygenetic origin for several ore districts but is not inclined to assign any significant concentration of ore substances even to ultrametamorphic processes.

The hypothesis of concentration of metals in connection with "secondary" magmatism has also been criticised by several authorities on ore deposits, including J. R. Hillebrand in a recent article (23). Since some of his critical remarks have a distinct bearing on the conditions discussed in this paper they will be considered in the following discussion.

With the hypothesis of an origin of ore deposits by ultrametamorphic processes two conditions are of ultimate significance: 1. The contents and associations of ore-forming elements in the granitized rocks. 2. The composition of the agents that have transported the ore materials. The first condition can be elucidated at least to a certain extent by field and laboratory information.

It has been questioned, whether the amount of dispersed metals in rocks is sufficient to produce concentrations such as those found in nature. Unfortunately our information concerning precentages of base metals in various rocks is very incomplete, but we know that the metals are fairly inhomogenously distributed and a concentration of various metals in bituminous sediments is a world-wide experience. Modern petrogenetical thought presumes cooperation between exogenic and endogenic processes in petrogenesis, and this has of course also been the basis for the ore-genesis reasoning in the present case. It is, therefore, not quite satisfactory to base a computation of masses of rocks that must have been mobilized merely on the values given as averages of the sial crust in geochemical handbooks. If a granitized rock mass contains a great amount of pre-metamorphic ore deposits these materials may of course be the source of the metals in post-granitic ores (in the sense of Scheneiderhöhn). But if a great mass of sediments contains (in a dispersed form) a metal in such amounts that it represents a concentration many times higher in relation to the sial average than the sum of the

[1] Lecture at a meeting of the Geological Society in Stockholm 1944.

presumptive ore deposits, the metals of the sediments might be the source as well.

Another point of general importance must also be considered. In most discussions of what could be called "rheomorphic ore genesis" only ore districts of high economic significance were considered. Now, since "ore formation" is a process of concentration of certain chemical elements, the process should be viewed in terms of concentration quotients, as a suggestion referred to the computed average of the various elements in the sial crust. Very large amounts of a certain chemical element may then be disregarded in the discussion because of its occurrence in a percentage range that does not give it interest to economic geologists. For an example we may consider iron. Large sedimentary iron-bearing rock masses with 15–25 percent of iron are known from various parts of the world, thus representing an exogenic concentration quotient of 3–5. A presumptive endogenic (or secondary exogenic) concentration by an additional two-fold concentration may bring them over to commercial ore, and the examples could be multiplied. If fractionation of various elements occurs in connection with granitization at all, different contents of the "ore-forming constituents" within granitized rock masses must influence the final result. Thus exogenic pre-metamorphic fractionation must have contributed to create concentrations and associations of elements which give the granitized rock portions its characteristic and, from one case to another, individual chemical and mineralogical features.

Very few accurate analytical data from Fennoscandia can be presented at the present as a basis of a discussion on more accurate grounds of the actual problems, and most of the following considerations are therefore based on the general petrological and mineralogical experience of the areas. However, a certain quantitative information can be gained from the publications by P. H. Lundegård (27) on the zinc contents in various rocks in central and southern Sweden. In spite of the zinc contents being highly varying even in the same group of rocks, there is a general tendency that lutitic sediments and older granites contain 100 to 200 gr/t more zinc than do leptites, gneisses and the late, palingenic granites. If one tries to estimate the amount of rock necessary for the formation of a zinc ore by the extraction of 100 gr/t from older rocks in connection with mobilization and refer the quantities to the present surface section it is found that a zinc deposit of 10,000 to 15,000 sq m and 10 percent zinc would demand a granitized area of 10 sq km. Since the areas of palingenic granites occupy areas of many thousands sq km and the gneisses still more, the author does not believe that quantitative considerations can be taken as controversy to a "mobilization hypothesis."

In the Skellefte District one of the significant conditions for the mobilization hypothesis as stated by Hillebrand is fulfilled: the mineralization is prior to the emplacement of the palingenic granites and is driven before and out of the progressing transformation front (as are the segregation pegmatites always prior to the homogenous granites).

The mineralization of the ore district as a whole is characterized by concentration of: 1. pyrite; 2. sphalerite; 3. arsenopyrite and, to certain degree,

antimony-bearing (sulpho-) minerals. Chalcopyrite is generally present, as was mentioned in the descriptive part, but there is a distinct provincial difference if one compares the ores of the Skellefte District with the sulphide mineralization in the vast volcanic-granite areas north of the Skellefte District proper. The northern mineralization has not yet been found to give rise to commercial ore deposits but it has a wide spatial occurrence. This mineralization is characterized by high chalcopyrite contents, as calculated in percentage of the total amount of sulphides, but low content of pyrite, sphalerite and arsenopyrite.

The change between these two sulphide mineralization provinces is remarkably abrupt—the Adak Area can be taken as a position where both types of mineralization are represented—and coincides in a remarkably manner with the wedging out of the graphite-bearing sediments and their metamorphic derivates. As was mentioned in the descriptive part, originally bituminous sediments are plentifully among this rock sequence. Since bituminous sediments commonly are apt to concentrate metal sulphides, especially iron sulphides, the pyrite dominance of the Skellefte District can be taken as significant of the mobilization hypothesis.

As regards the other constituents taken to characterize the two ore provinces mentioned, nothing definitely can as yet be said. Accurate and sufficiently numerous analyses of arsenic in rocks from the Skellefte District have not yet been performed because of analytical difficulties. It is worth mentioning, however, that the investigations of Goldschmidt and Peters (16) indicate a tendency to a concentration of arsenic in clay sediments, particularly where associated with hydrates and sulphides of iron.

In viewing the sulphide ores of the Central-Swedish ore district certain provincial divergencies from the ores of the Skellefte District can be discerned (probably less pyrite and arsenopyrite, higher lead/sphalerite quotient), but incomplete knowledge of the distribution of the actual metals in various rocks does not permit any conclusions concerning the cause of these divergences. The Gothian belt with its insignificant mineralization is of a general interest: Gneisses of various ages and derived from highly varying rocks certainly do occur, but amongst all these rocks those sedimentary types, which could be expected to cause considerable concentrations of sulphur and base metals are very sparsely represented.

The mutual distribution of the various ore minerals is also significant to the genetic problems. Commonly various sulphides are associated in a regular manner, e.g. in separate ore portions, but a zonal arrangement in relation to temperature zones or to a plutonite mass can extremely rarely be discerned. Especially in the Skellefte District various elements commonly appear in associations, which do not come far from the conventional zonal arrangement: viz. gold and arsenic—copper and arsenic—zinc (dominating) and lead—lead, (zinc), silver, antimony. This order also represents the most common order of precipitation. However, successions and associations of this kind are repeated in the various individual deposits, regardless of their position in relation to plutonites, metamorphic zones, or of the mineral facies as indicated by gangue or alteration minerals. Many of the deposits give

the impression, when considered as a whole, of a confused mixture of elements, which according to classical experience would tend to occur separately. As an example of deposits with geochemically remarkable mineral associations Boliden can be mentioned, where according to Ödman (29) three stages of mineralization have occurred, characterized by the following trends of concentration:

Stage 1: As, Au, Cu(?), Co, Ni, P, Ti
Stage 2: Cu(?), Bi, Se, Te, Au, Pb, Sb, Ag, B, F, (Mo, W, Cr, U)
Stage 3: Pyrite, Zn, (Sn). Chalcopyrite as principal copper mineral is present in all three stages which makes the position of copper in this scheme dubious.

Another remarkable association is offered by the small Lainijaur deposit (17) with a main pyrrhotite-pentlandite-chalcopyrite mineralization (connected with gabbro) of quite "normal" type, followed by a subsequent stage of mineralization characterized by Co-Ni-arsenides, scheelite, and molybdenite.

From the point of the mobilizing hypothesis the features described above mean that the fractionation process on a regional scale has been incomplete and has mainly been restricted to the individual deposits or groups of deposits or perhaps rather to their tectonical space of precipitation.

There is in fact a great agreement between the experience of the development of the granitization process and the mobilization of "ore materials": The first products of mobilization of the silicate rocks are pegmatitic segregations, which in chemical and mineralogical respect more or less distinctly reflect certain characteristics of the "mother rock," and which display but very local fractionation phenomena. Proceeding homogenization and, at least at places, fluidization presumably causes granites, from which in turn postgranitic pegmatites have segregated, then with few features that can tell anything about the details of the mother rock. From the point of the "mobilization hypothesis" it seems quite reasonable that fractionation processes in mineralization of a postgranitic age are more complete and tend to develop according to more regular and consistent lines.

In the Skellefte District one can in fact discern a tendency to spatial mineral zoning in one or two cases. According to Grip (personal communication) a certain zonal distribution is indicated at the border of the granite tongue immediately west of Boliden (Fig. 2): Pure pyrite-pyrrhotite concentrations occur next to the granite and outwards first copper-dominant and then zinc-dominant mineralization appears. A similar distribution of minerals is indicated by the sulphide deposits west of the westernmost granite tongue. It is significant that such conditions are found to be connected with those granite protrusions, which represent the most clearly intrusive, and from the very gneiss-granite front most remote portions of the granite mass.

The second condition to be considered in a discussion of mobilization and concentration of ore minerals in connection with granitization is the influence of the composition of the transporting agents. Here, information is even more incomplete, but certainly this is a question of high importance. Constituents in a transformed rock, which under certain circumstances are not attacked at all, may under different conditions be mobilized and reprecipitated.

Such conditions may of course be a cause of the divergency of final results of transformism in various districts.

For example, consider the distribution of tin. In spite of the abundant occurrence of pegmatites in the Archaean areas of Fennoscandia tin deposits do not occur. From the mobilization hypothesis this fact may be due either to a scarcity of tin in the mobilized rock masses or to the absence of agents necessary for a high-grade concentration of a dispersed tin content (e.g. fluorine in sufficient amounts). Very little is known concerning the content of tin in Fennoscandian rocks, but some sporadic observations can be taken to indicate that they should not be considered a portion of the sial crust particularly poor in tin: 1. Landergren (25) has found a considerable concentration of tin in the Grängesberg iron ores (as compared with the average tin content in the sial crust); 2. In the Skellefte District stannite was observed in several pyrite ores; 3. Cassiterite has been observed in association with palingenic Svecofennian granites. In this connection it is worth recalling that the only cassiterite ore found in Fennoscandia, Pitkäranta, is connected with Sub-Jotnian Rapakivi granites, which are known to be characterized by higher and more consistent contents of fluorite than other granites of Fennoscandia. The Rapakivi granites are in several respects quite different from the palingenic granites discussed above and most certainly have a different history of origin—the example is given only to emphasize the fact that a concentration of tin is accompanied also in Fennoscandia by a coexistent concentration of fluorine.

In the above discussion, sulphide ores mainly have been considered. One may of course ask what happens to the iron ores. A review of the Swedish iron ores and of their genetic problems has been presented by P. Geijer and N. H. Magnusson (15). A common feature of the Svecofennian iron ores is that the concentration of the iron has occurred principally prior to the emplacement of the older Svecofennian granites. In central Sweden the iron ores are bound to the lower supercrustal division, the leptite formation, characterized by the occurrence of limestones and acid volcanites. In the upper supercrustal division, where originally lutitic sediments, very often of the graywacke series type, are prevalent, limestones and iron ores are practically lacking.

The iron ores of central Sweden were divided by Geijer-Magnusson into three main groups: quartz-banded ores, skarn and limestone ores, and apatite ores. The first group belongs to the world-wide Precambrian type of ore known as "banded ironstones" and is assumed to represent chemical sediments. The skarn and limestone ores display many features considered as characteristic of contact-metasomatic ores, viz. mineralogical composition and epigenic structural features. The apatite ores represent a well-defined group in mineralogical and chemical respect and are still more distinctly epigenic than the skarn ores.

Several of the skarn and limestone ores could be shown to have been derived from the sedimentary ores—their mineralogical composition being due to metamorphism. The epigenic features, which commonly give the impression of a replacement front in limestone, and/or skarn rocks, can in such cases be described as a kind of "pseudometasomatism." Even fairly weak

metamorphism may cause a mobilization and concentration of iron from quartz-banded ores, as was illustrated by Geijer (14a) in a very illuminative example from the Stripa mine. The banded ore is transformed into a massive, high-grade ore by hydrothermal extraction of quartz and transformation of parts of the hematite into magnetite, and the contact relations have very much the appearance of a metasomatic replacement front.

There is still a certain divergency between various authorities of the iron ores concerning the role that can be assigned to a supply of iron from magmatic hydrothermal solutions, but these problems will not be touched upon since the object here is merely to examine the effects caused by the high-grade metamorphism, which leads to veined gneisses and palingenic granites. It is seen from the map, Figure 1, that iron ores do occur within gneiss areas, though they are rare. The scarcity of iron ores within the gneiss regions is due to the fact, that the dominant portions of the gneisses have been derived from the sedimentary division bare of iron ores. Metamorphism may have caused mineralogical changes and local mobilization of ore materials, but in the main not to an extent as to obliterate the original stratigraphic positions of the ores. Consequently, metamorphism, which is assumed to have caused "rheomorphic" sulphide ores, gives rise only to local "pseudo-metasomatic" phenomena in the iron oxide ores.

The author is well aware that the above interpretations can be looked upon as a working hypothesis only, and that, when ore genesis on a more global scale is considered, arguments can be presented that at least at first sight seem to be inconsistent with the hypothesis. It may be questioned, for instance, why in places granitized and gneissic bituminous sediments are found without any association with more remarkable pyrite mineralization, or why all over the world are so many sulphide deposits similar to those discussed in this paper, apparently independent of any kind of previous exogenic concentration. It may also be argued that many factors, even the tectonic development, may contribute to certain provincial characteristics of ore districts. To all this it can be said that each case must first be treated separately with consideration to its specific conditions, and that in most cases it is not possible to deduce the source of both plutonic rocks and the metal concentration genetically connected with them. In this respect conditions in the Skellefte District and adjacent areas are favorable, provided the interpretations of rock genesis of the district as given in this paper are correct, and they may therefore be taken as a contribution to the actual discussion on the formation of ore deposits by mobilization by high-grade metamorphism of dispersed substances in solid rocks.

MINERALOGICAL DEPARTMENT,
UNIVERSITY OF STOCKHOLM,
July 23, 1955

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INVESTIGATION OF THE COKING PROPERTIES OF COAL BY VACUUM DIFFERENTIAL THERMAL ANALYSIS

LEWIS H. KING AND DANFORD G. KELLEY

ABSTRACT

Vacuum differential thermal analysis has been used to study the coking properties of a number of bituminous coals. Samples of 200 mgs were run from room temperature to 600° C at a heating rate of 10°/min.

The thermograms show two peaks that can be related to the plastic properties: (1) a strong exothermic peak beginning between 340–440° C and reaching a maximum height between 440–520° C; (2) a small, sharp exothermic peak superimposed on the limb of the larger peak and occurring between 430–500° C. The beginning of No. 1 peak represents the softening temperature of the coal while its summit corresponds to the solidification temperature. No. 2 peak occurs in the temperature zone of maximum fluidity and maximum rate of swelling. The sharpness of this peak appears to be influenced by the fluidity of the coal.

The changes that occur in the plastic properties of a coal through blending with other coals can be detected on the thermograms and in the small coke buttons formed in the thermocouple well. For example, by blending a high-volatile A coal with increasing amounts of a low-volatile coal, No. 2 peak occurs at progressively higher temperatures, diminishes in intensity and finally disappears. The coke buttons show changes in their cellular structure and degree of swelling.

The thermograms and coke buttons can also be modified by the addition of diluents such as fusain, silica gel, quartz, clay, sulfur, charcoal, various inorganic salts and phenanthrene. The degree to which the thermal curves are affected depends on the type and amount of diluent, as well as the properties of the original coal.

In an effort to obtain a yardstick by which the coking properties of a coal can be determined, a number of laboratory methods have been devised. The conventional methods include volatile-matter determination, small scale coking tests, and various measurements on the behavior of a coal while in the plastic state. By correlating these results with the behavior of similar coals in a coke oven it is often possible to make a preliminary estimate of the coking properties of a new coal or blend.

It now appears that differential thermal analysis can be used for studying the coking properties of coal. The main purpose of this investigation is to interpret the thermal curves through correlation with well known methods and it is not suggested that differential thermal analysis can adequately replace the better known techniques for studying the coking properties of coal. Furthermore, it is believed that much more work is necessary before the merits of this technique can be completely evaluated. The results of this investigation show: (1) differential thermal analysis can be used to study some of the plasticity characteristics affecting the behavior of a coal during

carbonization; (2) the sample can be recovered from the thermocouple well and studied by direct observation to give an indication of the nature of the coke; (3) the method can be used as a convenient research tool in observing the effects of blending, addition of diluents, and weathering on the coking properties.

EXPERIMENTAL TECHNIQUE AND MATERIALS

The vacuum differential thermal analysis equipment used in this investigation has been previously described by Whitehead and Breger (10).

More recently, Glass, (2) and Stott and Baker (9) have carried out investigations on coal using equipment of a more conventional type, in which a vacuum is apparently not required. The curves for bituminous coals illustrated by Stott and Baker compare remarkably well with those of this report in the temperature range from 20–550° C even though the former were run in air. For this investigation it was essential to use a vacuum or inert atmosphere, otherwise the results could not be duplicated, due to oxidation of the sample as it was heated. This is probably caused by the fact that the furnace is of radiation type and permits the air to circulate more freely than in the conventional type of furnace.

Samples of 200 mg size were run from room temperature to 600° C at a heating rate of 10° C/min. The thermocouple well that contained the sample was first packed with alumina up to the head of the thermocouple. Minus 200 mesh coal was then firmly packed into the remaining space in the well. This procedure prevented the sample from sticking to the thermocouple during the run, and thus facilitated the removal of the coke button without

TABLE I

LOCATION OF SAMPLES

Sample No. (corresponds to No. on Thermogram)	U.S. Bureau of Mines Coal No.	Bed	County	State	Mine
1	692	Pocahontas No. 3	McDowell	W. Va.	Keystone
2	622	Pocahontas No. 9	McDowell	W. Va.	Page No. 9
3	555	Pittsburgh	Washington	Pa.	Mathies
4	627	Windrock	Anderson	Tenn.	Jackson Bros.
5		Harbour	Cape Breton	Nova Scotia	Princess
6		Backpit	Cape Breton	Nova Scotia	Greener
7	679	Smith	Harlan	Ky.	Fighting Crap
8	685	Creech	Harlan	Ky.	No. 6
9	678	Lower Sunnyside	Carbon	Utah	—
10	671	No. 7	Green	Ind.	Friar Tuck
46			Sullivan	Pa.	
47	M.I.T. Sedimentology Collection S14–67				
48			Schuylkill	Pa.	
49				R.I.	
52			Sheridan	Wyo.	Masters No. 1 Big Horn Coal Co.
53		Toledo-Castle Rock coal		Wash.	Idleman
54		Wyodak coal	Campbell	Wyo.	
55			Lincoln	Wyo.	Brilliant No. 8

TABLE II

ANALYSIS OF COAL SAMPLES AND INFORMATION OF THE QUALITY OF THEIR COKE

Sample No. (corresponds to No. on Thermogram)	Proximate, percent				Ultimate, percent					Rank	Strength of coke (ASTM method)			Quality of coal in terms of coking
	Moisture	V.M.	F.C.	Ash	H	C	N_2	O_2	S		Shatter index 1½"×1"	Tumbler 1"	Indices ¼"	
1*	3.3	16.9	73.6	6.2	—	—	—	—	.6	L.V.	—	—	—	Good coking coal
2	4.2	17.9	66.9	11.0	4.6	76.2	1.2	6.3	0.7	L.V.	88	49	62	Good coking coal
3	2.0	37.3	55.2	5.5	5.4	78.2	1.6	7.8	1.5	HVA.	78	37	59	Good coking coal
4	2.5	37.4	55.3	4.8	5.4	77.4	1.9	9.7	0.8	HVA.	67	20	63	Medium coking coal
5	2.6	37.1	55.1	5.2	5.4	77.7	1.6	8.5	1.6	HVA.	—	—	—	—
6	3.8	35.8	50.0	10.4	—	—	—	—	5.4	HVA.	—	—	—	—
7	3.9	37.7	50.7	7.7	5.4	72.7	1.7	10.7	1.8	HVA.	76	22	56	Medium coking coal
8	3.0	39.2	51.7	6.1	5.0	75.6	1.8	9.7	1.8	HVA.	55	6	55	Poor coking coal
9	5.8	37.1	49.6	7.5	—	—	—	—	1.2	—	45	40	—	Poor coking coal
10	13.6	31.8	39.4	15.2	5.4	57.9	1.2	19.3	1.0	HVC.	85	27	43	Poor coking coal
46										Semi-anthracite				
47										Anthracite				
48										Anthracite				
49										Sheared Anthractie				
52										Subbituminous				
53										Subbituminous				
54										Subbituminous				
55										Subbituminous				

* Coke not tested, but similar to 2

breakage. The sample was permitted to swell in one direction during coking as no sample-block cover was used. At the end of each run the furnace was cooled under vacuum, after which the coke button was removed and impregnated with Bakelite resin TR 9332. The specimen was then mounted in a Lucite pellet, polished, and examined microscopically. A Vickers Projection Microscope was used to obtain low and high-power photomicrographs of a number of these specimens (Plates 1–5).

The locations of the coal samples used in this investigation are given in Table I. Table II gives their chemical analysis and information on the quality of their coke. There is reason to believe that samples 7–10 were slightly oxidized by the time the differential thermal analyses were made.

THERMOGRAMS OF COKING COALS

The changes that occur in coal during carbonization are complex and are incompletely understood. From a structural point of view it is relatively certain that when coal passes through the plastic state during coking, the secondary van der Waals forces bonding the coal micelles become replaced by primary bonds as the coke is formed. It is also known that the organic molecules of the coal substance undergo destructive distillation and that these reactions proceed most rapidly as the coal is going through the plastic zone. Many of these reactions are possibly exothermic. The large amount of hydrogen present in coke-oven gas strongly indicates that the reactions that take place are exothermic owing to dehydrogenation (6). Large-scale operations indicate an exothermic heat of 200 Btu per lb of coal during carbonization while laboratory investigations show results of 40 to 50 Btu. It is not known if these figures truly represent exothermic heat, so it must be concluded that the actual exothermic heat in the carbonization process has not been definitely established. The thermograms of coking coals illustrated in this report all support the idea that carbonization is an exothermic process. Furthermore, previous work by Whitehead, (11) Breger, (1) King (3) and Stott (9) shows that the major thermographic peaks for bituminous coals are exothermic.

Curves 1–10 (Fig. 1) represent various grades of coking coals and with the exception of curves 7, 9 and 10 they show the same general features. Between room temperature and 600° C, the thermograms show two important exothermic peaks both of which are related to the plastic properties of the coal. These peaks are referred to as peak No. 1 and peak No. 2.

Peak No. 1 is the major peak generally beginning between 340 and 440° C and reaching a maximum height between 440 and 520° C. The curves in Figure 1 show that the temperature spread between the beginning and summit of this peak can be as great as 125° C and as small as 45° C. Further work on different coals will probably reveal that this temperature spread can be even greater.

Peak No. 2 is always much smaller than No. 1 and occurs superimposed on the limb of the larger peak within the temperature range 430–500° C. Curves 7, 9 and 10 reveal that this peak is not present in coals that are

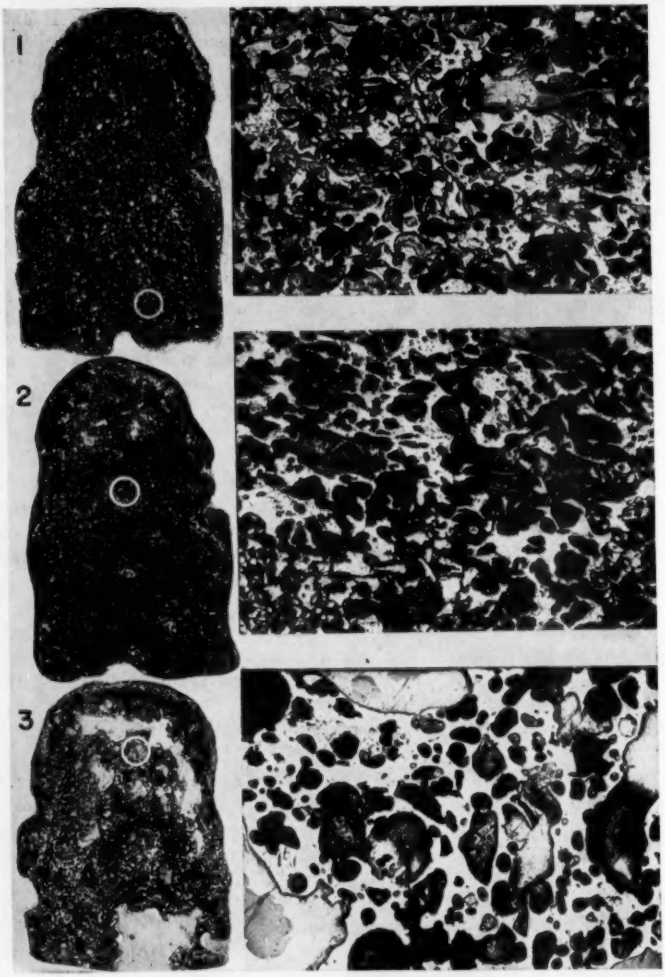

PLATE 1

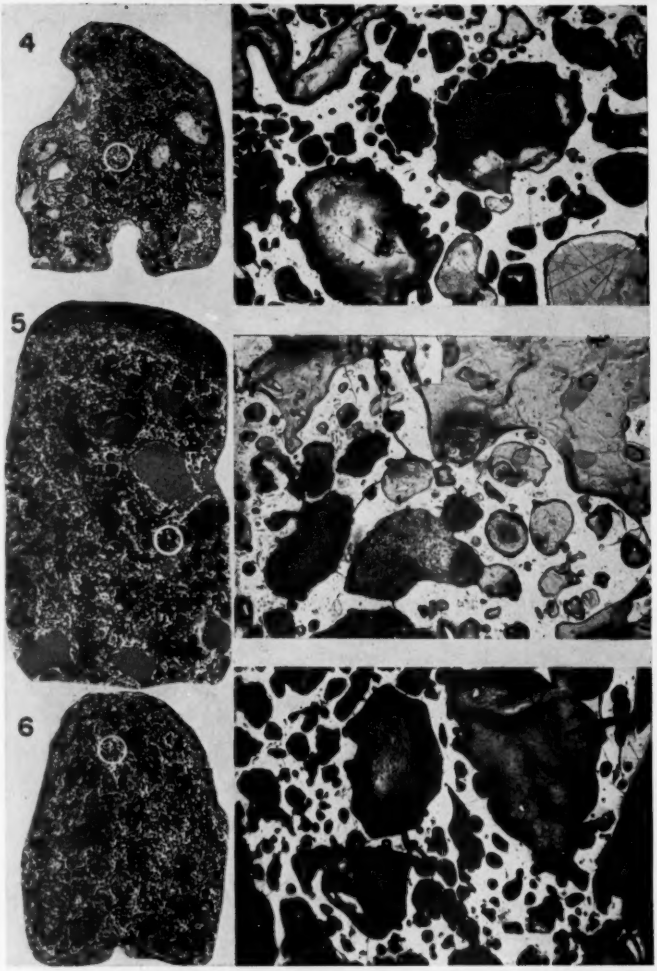

PLATE 2

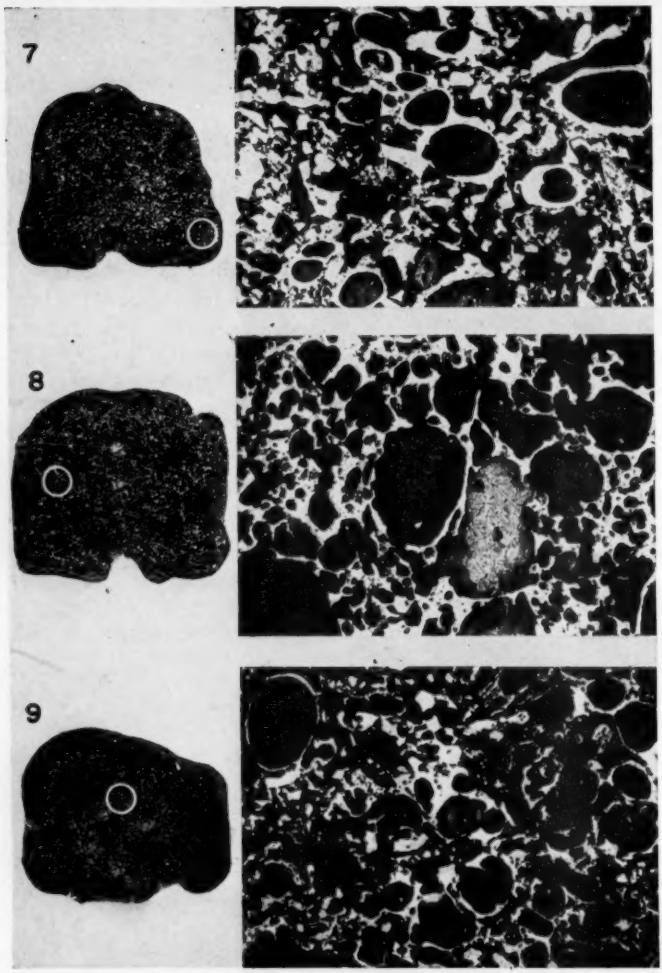

PLATE 3

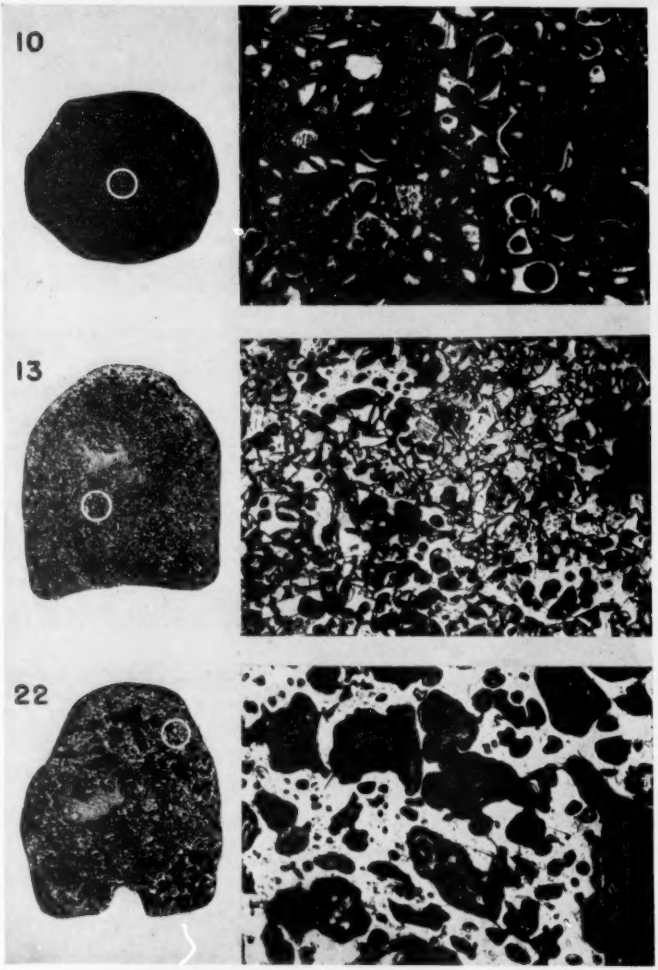

PLATE 4

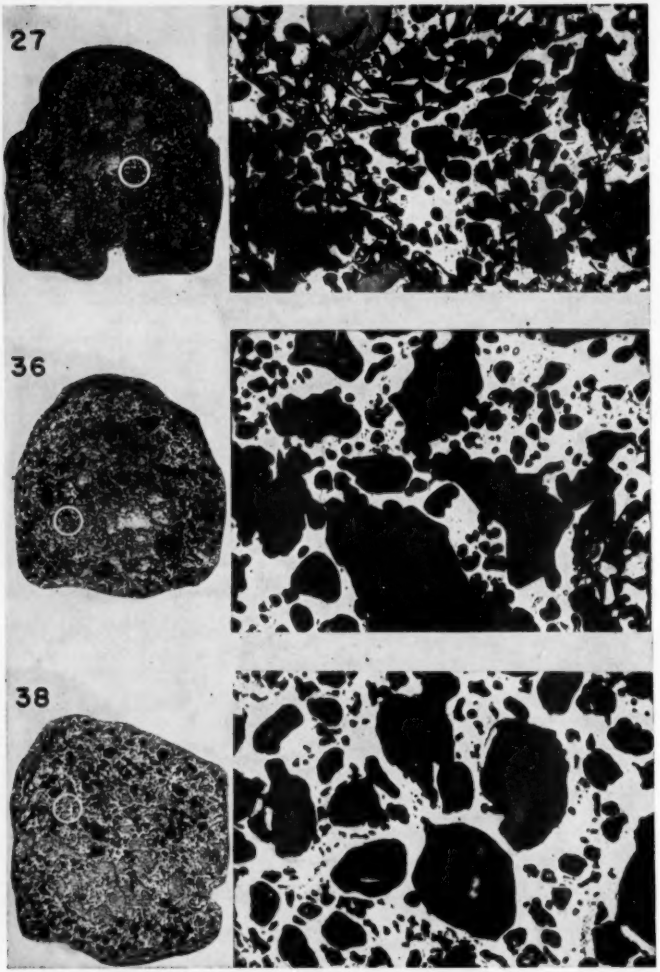

PLATE 5

weakly coking. Table II shows that sample 7 produced a medium grade coke and samples 9 and 10 a poor grade coke at the time they were tested by the U. S. Bureau of Mines. Possibly as a result of oxidation, these samples had lost much of their coking ability when the thermograms were prepared.

Through correlation of the thermographic data with plastometer and heating microscope measurements, it is thought that the beginning of peak No. 1 represents the softening temperature of the coal while its summit cor-

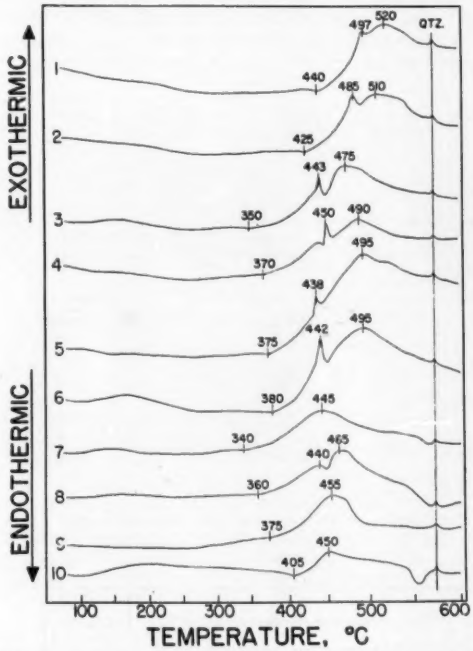

FIG. 1. Thermograms of coking coals: 1 (L.V.) (Good coking coal), 2 (L.V.) (Good coking coal), 3 (HVA.) (Good coking coal), 4 (HVA.) (Medium coking coal), 5 (HVA.), 6 (HVA.), 7 (HVA.) (Medium coking coal), 8 (HVA.) (Poor coking coal), 9 (Poor coking coal), 10 (HVC.) (Poor coking coal).

responds to the solidification temperature. It is also believed that No. 2 peak occurs when the sample reaches the zone of maximum fluidity and maximum rate of swelling.

Plastometer measurements are only available for samples 3 and 8 and data for this material is tabulated in Table III. In Table IV a comparison is drawn between the plastometer and thermographic data on softening, maximum fluidity and solidification. Agreement between the different meth-

ods is good for the softening and solidification temperatures, the greatest difference between any two measurements being 11° C. The measurements on maximum fluidity show a good correlation between the thermographic and Davis methods, but the results of the Gieseler plastometer are lower.

The plastic zone occurs at higher temperatures on curves 1 and 2 (Fig. 1) than on the remaining eight curves. This is explained by the fact that

TABLE III

PLASTIC PROPERTIES OF COALS

Sample No.	Initial softening temp.	Fusion temp.		Maximum fluidity				Solidification			Plastometer, resistance ends, °C
				Gieseler plastometer maximum pointer movement		Davis plastometer, minimum resistance			Davis plastometer, maximum resistance		
	Gieseler plastometer, at 0.1 dial division, °C	Gieseler plastometer at 5.0 dial divisions per minute, °C	Davis plastometer, resistance develops, °C	°C	Div. per min.	°C	Lb.-in.	Gieseler plastometer, no further dial movement, °C	°C	Lb.-in.	
3	356	398	399	422	4,650	436–46	0.8	476	475	14.8	517
8	360	407	—	424	2,655	—	—	454	—	—	—

curves 1 and 2 are for low-volatile coals while the other curves represent high-volatile coals. This observation is consistent with the results of other workers using different methods (5).

The intensity and sharpness of peak No. 2 appears to be influenced by the fluidity of the coal, but this observation is not always apparent. Curves 3–6 are for high-volatile A coals which have a relatively high fluidity. In

TABLE IV

COMPARISON OF PLASTOMETER AND THERMOGRAPHIC DATA

Sample No.	Softening temp., °C		Max. fluidity temp., °C			Solidification temp., °C		
	Gieseler plasto-meter	Temp. at which Peak No. 1 begins	Gieseler plasto-meter	Davis plasto-meter	Temp. at which Peak No. 2 occurs	Gieseler plasto-meter	Davis plasto-meter	Temp. at which Peak No. 1 reaches its max. height
3	356	350	422	436–446	443	476	475	475
8	360	360	424	—	440	454	—	465

these four cases, peak No. 2 is sharp and well defined. Curves 1 and 2 are for low fluidity, low-volatile coals and, as expected, peak No. 2 is rounded and less pronounced. Curve 8 represents a high-volatile coal with a maximum fluidity of 2,655 dial divisions per minute by the Gieseler plastometer, so that one would expect peak No. 2 to show a greater degree of sharpness. It is possible that the sample became slightly oxidized prior to the thermographic determination.

It is well known through previous plastometer investigations that the fluidity of a coal can be reduced by blending with low-volatile coals or by the addition of inert material. It will be seen later that peak No. 2 in many of the curves in Figures 4–6 is modified by blending and by the addition of foreign material—a fact which further substantiates the opinion that peak No. 2 is closely related to the maximum fluidity of the coal.

The swelling behavior of coals 2, 3 and 5 was studied with a recently developed Leitz Heating Microscope. The samples were prepared in the form of a cylindrical pellet about 1 mm in diameter and heated from room temperature to 800° C in an atmosphere of N_2. The optical system is arranged in a manner to permit projection of a silhouette of the sample on a screen at approximately 15 × magnification. The swelling process was re-

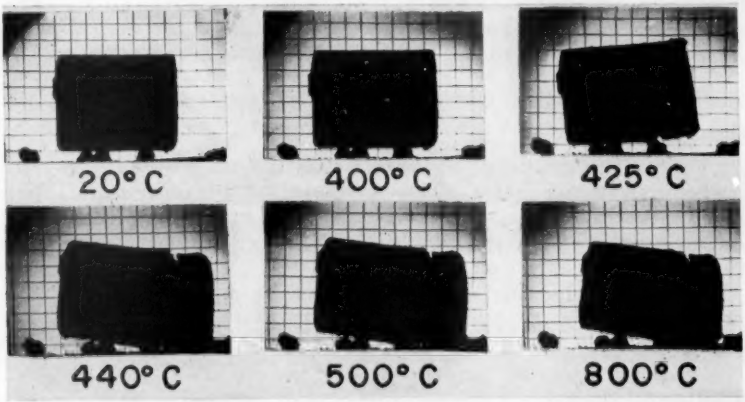

FIG. 2. Series of silhouette photographs of a pellet of sample 5 being heated from room temperature to 800° C in a Leitz Heating Microscope. Area determinations were made on similar prints for preparation of the swelling curves of Figure 3. Magnification approximately 15 ×.

corded by photography, the temperature being noted at the time each photograph was taken. (Fig. 2.) Area determinations were made from the photographic prints after which the swelling curves (Fig. 3) were prepared. A comparison between the thermal and swelling curves shows that peak No. 2 falls within the temperature zone of the maximum rate of swelling. The results are tabulated in Table V.

During the course of the experiments it was found more convenient to use a heating rate of 20° per minute rather than the 10° per minute rate used for the Harbour sample. The faster heating rate caused a much greater degree of swelling but did not change the peak temperatures by more than 10° C. It is interesting to note from the swelling curves that the coke begins to shrink before the solidification temperature is reached.

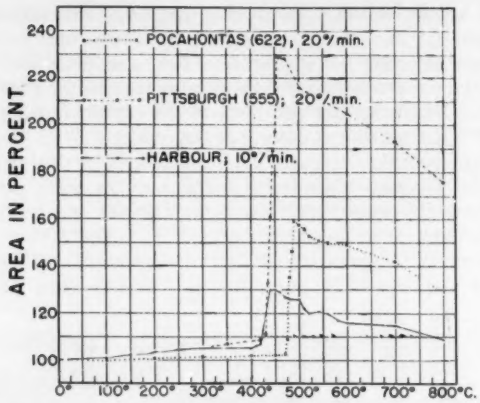

FIG. 3. Swelling curves: sample 2 (Pocahontas), sample 3 (Pittsburgh) and sample 5 (Harbour).

Further investigation of Figure 1 reveals that the curves fall in three general categories or groups. These categories are defined by the following criteria: the temperature at which the peaks occur, the height of peak No. 1, the presence or absence of peak No. 2, and the sharpness and intensity of peak No. 2.

Group No. 1 includes 1 and 2 for the following reason: both peak No. 1 and 2 occur at higher temperatures than in the other curves, peak No. 1 is high and peak No. 2 is rounded and not as well defined as in curves 3–6.

TABLE V

Sample No. and name	Peak No. 2 °C	Zone of max. rate of swelling °C
2 Pocahontas No. 9	485	470–490
3 Pittsburgh	443	430–455
5 Harbour	438	420–440

Group 2 includes curves 3–6 on the basis that both peaks appear at lower temperatures than those of curves 1 and 2. Peak No. 2 is high, sharp and clearly defined.

Group No. 3 includes curves 7–10. These curves are characterized by the low height of peak No. 1, lower temperatures for the summit of peak No. 1, and absence of peak No. 2 with the exception of curve 8. Actually, curve 8 is intermediate between groups 2 and 3 but possibly resembles the latter to a greater extent.

As previously mentioned, coke buttons were obtained after each run and examined microscopically. Photomicrographs of samples 1–10 appear in Plates 1–4. The numbers on these plates correspond to the numbers on the thermal curves and samples. Macroscopic views of the entire coke button

appear on the left-hand side of each plate at a magnification of 6 ×. A microscopic view, taken at some point within the white circle on the macroscopic view, is shown to the right of each button at a magnification of 75 ×. The white areas on the photos represent coke. With good coking coals the pores are represented by either the gray, or black areas depending on whether or not the pores are filled with resin. With poor coking coals most of the black areas are uncoked residues.

Both the macroscopic and microscopic views are necessary for an adequate description of the coke structures. A qualitative analysis of these structures shows that the same three general groups of samples that were noted in the thermograms can also be recognized in the coke buttons. It is possible that a quantitative analysis of the cellular structure might reveal significant differences within these groups.

Photos 1 and 2 constitute group No. 1 and are characterized by small shallow pores which show a limited size distribution. The impression gained through examination of both the macroscopic and microscopic views is one of a dense aspect.

Group No. 2 includes photos 3–6. These cokes have a much wider size distribution of pores. The larger pores are surrounded by many small ones, giving what appears to be a bimodal distribution.

Group No. 3 consists of photos 7–10. The variations within this group are much greater, so that further division might be warranted. Nevertheless, they all show one common feature, namely a ring-like structure that appears in various degrees of development. Photo No. 10 shows the ring-like development with black areas in between where the sample was too friable to take a polish. This characteristic structure is well developed in photos 7 and 9, but once again, the areas between the rings do not have a clear-cut cellular structure as observed in normal coke. Instead, they have a fragmental aspect. As in the case of the thermogram for sample 8, photo No. 8 appears to be intermediate between groups 2 and 3. Although, it shows the typical ring-like structure of group 3, the areas between these structures show a more normal cellular development.

The relative heights of the coke buttons as shown by the macroscopic photos are not truly indicative of the degree of swelling shown by the various samples. The majority of the coke samples were covered with a layer of non-coking material when they were removed from the thermocouple well and this material was scraped off before the pellets were mounted and polished. As a result the true height of the button is not shown by the photos.

In Table II the quality of the coke produced by the various samples is expressed in terms of good, medium and poor coking coal. These determinations were made by the U. S. Bureau of Mines. It is difficult to establish a direct correlation between the Bureau of Mines results and those presented in this report since no standards have been set for the latter. Nevertheless, it is possible to point out some of the variances between the two sets of data. Samples 1–3 are considered to be good coking coals. Assuming that the structural patterns shown by these samples in photos 1–3 are representative of good coking coal, then samples 4 and 7, which are medium coking coals,

should show a different type of structure. The actual results shown by photos 4 and 7 reveal that this is not the case, since photo No. 4 is not significantly different from photo No. 3 (good coking coal), while the difference shown by photo No. 7 appears to be too large. It is quite possible that these inconsistencies might be the result of oxidation of two or more of these samples. In the case of samples 8–10 (poor coking coals), the photos reveal the peculiar ring-like structure, which might well be indicative of poor coke. Until many more samples of various types of coking coals have been run, it will not be possible to evaluate fully the possibilities of using differential thermal analysis as a method for classifying coals with regard to the quality of coke they produce. Much more work along similar lines is warranted.

THERMOGRAMS OF COAL BLENDS

Previous investigations have shown that plastometers are useful in observing the effect of blending on the coking properties of coal. For example, it has been shown that through blending, the plastic properties of coal become quite transient (5, 8). A study of thermograms 11–21 (Fig. 4) reveals that similar trends in the plastic properties of coal can also be observed by using differential thermal analysis.

Curves 11–19 (Fig. 4) represent different mixtures of samples 2 and 3 which are low and high-volatile coals respectively. The curves for samples 2 and 3 are repeated in this diagram for convenience in making comparisons. The most striking feature about this series of curves is the general shift of the peaks toward higher temperatures as increasing amounts of low-volatile coal are added to the high-volatile coal. A 10 per cent addition of low-volatile coal advances the softening point of the high-volatile A coal by 20° C (curve 11). Curve 14 is for a 50–50 mixture and shows the softening points of both coals at 380 and 420° C. As larger amounts of low-volatile coal are added the softening point for the low-volatile coal becomes more definite whereas the softening point for the high-volatile coal gradually disappears. Peak No. 2 of the high-volatile coal can be traced in a similar manner down to curve 12 (25% dilution) but becomes obscure beyond this point. Peak No. 2 for the low-volatile coal is only present in curves 2 and 19 (10% dilution in the latter). This shows that the low-volatile coal is more sensitive to blending than the high-volatile A coal. The intermediate curves 13–18 have not been interpreted but show a number of features that might prove to be of interest once they are understood. Photo No. 13 (Plate 4) is indicative of the type of coke that forms from these intermediate samples. These cokes show much fragmental material, which is indicative of a low degree of fluidity.

Curve 20 is for a blend of samples 3 and 5 both of which are high-volatile A coals. A comparison of this curve with curves 3 and 5 (Fig. 1) shows that it has assumed the softening point of sample 3 and the solidification point for sample 5 while the temperature of maximum fluidity has remained about the same. Curve 21 represents a mixture of samples 5 and 6;

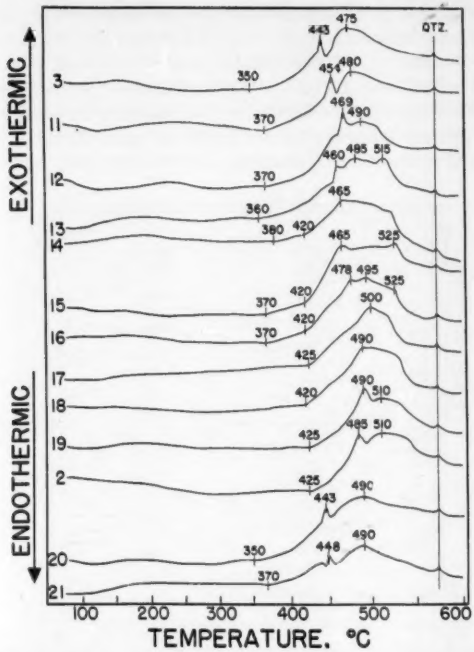

FIG. 4. Thermograms of coal blends: 2 (100% L.V.), 3 (100% HVA.), 11 (90% sample 3—10% sample 2), 12 (75% sample 3—25% sample 2), 13 (60% sample 3—40% sample 2), 14 (50% sample 3—50% sample 2), 15 (40% sample 3—60% sample 2), 16 (32% sample 3—68% sample 2), 17 (25% sample 3—75% sample 2), 18 (17% sample 3—83% sample 2), 19 (10% sample 3—90% sample 2), 20 (75% sample 3—25% sample 5), 21 (50% sample 5—50% sample 6).

both high-volatile A coals. The result is very similar to that obtained in curve 20.

The thermograms of Figure 4 illustrate that the differences in both rank and plastic properties between two coals used in a given blend are very important. In a case where the differences are quite large the plastic properties of tne blend become quite transient but few changes occur in blends where coals of similar rank and plastic properties are used.

THERMOGRAMS OF COKING COALS TO WHICH DILUENTS HAVE BEEN ADDED

The thermograms and coke buttons of bituminous coals can also be modified by the addition of diluents such as fusain, silica gel, quartz, clay, sulfur, charcoal, various inorganic salts, phenanthrene and probably many other organic and inorganic materials.

The thermograms of Figure 5 illustrate the influence of varying amounts of fusain on three different coals: samples 3 and 5 (high-volatile A) and sample 2 (low-volatile). Additions of fusain to sample 5 in increasing amounts cause a decrease in fluidity, an increase in the temperature at which maximum fluidity occurs, a decrease in the temperature range of the plastic zone and a continual lowering of the height of peak No. 1. Similar results are also obtained in the case of samples 3 and 2, however, smaller amounts of

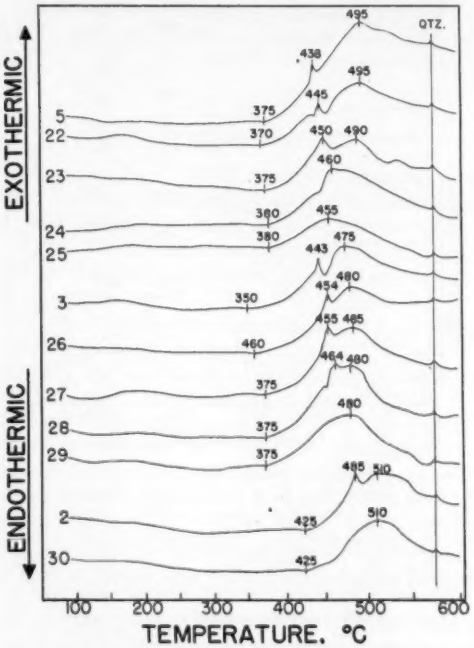

FIG. 5. Thermograms of coals diluted with fusain: 22 (sample 5 with 10% fusain), 23 (sample 5 with 20%), 24 (sample 5 with 30%), 25 (sample 5 with 40%), 26 (sample 3 with 5%), 27 (sample 3 with 10%), 28 (sample 3 with 15%), 29 (sample 3 with 20%), 30 (sample 2 with 10%).

fusain are required to erase peak No. 2. Although both samples 3 and 5 are of the same rank, sample 5 is a strong swelling coal which might account for the fact that 30–40 percent fusain is required to eliminate peak No. 2 while the same result is obtained with sample 3 by the addition of 15–20 percent fusain. The fact that sample 2 requires less than 10 percent fusain might be explained by its higher rank.

A comparison of photos 22 and 27 with photos 5 and 3 respectively illustrate that the addition of fusain brings about a greater degree of denseness

to the coke. However, a point is eventually reached where further addition of fusain renders the coal non-coking.

It is now known that the amount of diluent, as well as the properties of the original coal influence the thermal curves. Curves 31–39 (Fig. 6) and Table VI show that in addition to these factors, the type of diluent is also important. In the case of the inert diluents, the specific surface of the material appears to be an important factor influencing the modification of the

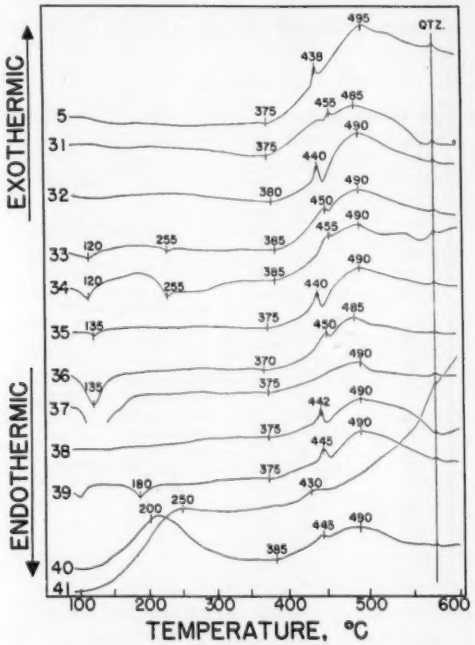

FIG. 6. Thermograms of sample 5 to which various diluents have been added: 31 (10% silica gel), 32 (10% quartz), 33 (2% sulfur), 34 (5% sulfur), 35 (0.5% boric acid), 36 (1% boric acid), 37 (5% boric acid), 38 (1% sodium oleate), 39 (5% phenanthrene), 40 (sample 5 run in air to 200° C and then in vacuum to 600° C), 41 sample 5 run in air).

plastic properties. The wettability of this surface might also be important. Curves 22, 31 and 32 represent samples of coal containing 10 percent fusain, silica gel, and quartz respectively. Using the temperature change in peak No. 2 from the original sample as a criterion for judging the degree of modification of the plastic properties, it is noted that the diluents occur in the following order of decreasing effectiveness: silica gel, fusain and quartz.

This is also thought to be the order of decreasing specific surface of the diluents.

The relative influence of the other diluents used in this investigation appears to depend to a large degree on whether or not they have a melting point below or react with the coal before the carbonization temperature is reached. Diluents which do not react with the coal and which have melting points above the plastic range do not show a pronounced influence on the thermograms when added in small quantities.

Surfur is an effective diluent and curves 33 (2% S) and 34 (5% S) show that this material reacts with the coal at 255° C. Even more effective is

TABLE VI

RELATIVE EFFECT OF DILUEUNTS ON PEAK NO. 2 OF SAMPLE 5

Diluent	Amount %	Temp. change in Peak No. 2 from the original sample °C	Remarks
NaCl	5	0	m.p. 801° C
NaCl	20	3	
KOH	2	Peak erased	m.p. 360° C
KNO_2	5	Peak earsed	Strong exothermic reaction at 325–410° C m.p. 387° C
KNO_3	5	Peak erased	Strong exothermic reaction at 390–470° C m.p. 334° C
$SnCl_2$	5	Peak erased	m.p. 246° C
$CaCO_3$	5	0	Sublimates at 898° C
$AlCl_3$	5	5	Sublimates at 178° C
$MgCl_2(6H_2O)$	5	7	Decomposes 116–118° C
KAc	5	Peak erased	m.p. 292° C
K_2CO_3	5	2	m.p. 891° C
$(NH_4)_2SO_4$	5	Peak erased	Decomposes 100° C
NH_4Cl	5	8	Sublimates 350° C
Quartz	30	5	
Bentonite	10	4	
Charcoal	10	8	

boric acid (curves 35, 36, 37), 0.5% of which causes a shift of peak No. 2 by 12° C. It is not known if the endothermic reaction at 135° C represents a breakdown of the diluent or a reaction with the coal. A comparison of photos 5 and 36 shows a considerable reduction in pore size in the latter which is caused by the addition of 1 percent boric acid. Similar effects in both the curve (No. 38) and coke button are observed when sodium oleate is added to sample 5 in small quantities. Its melting point occurs at 232–5° C which possibly explains its effective nature as a diluent. When sample 5 is mixed with phenanthrene (curve 39) the thermal curves are also modified considerably. This material has a melting point at 97° C and also reacts with the coal at 180° C. As is shown later, this reaction temperature varies with different coals.

The relative effectiveness of other diluents used in this investigation is shown in Table VI.

EFFECTS OF OXIDATION ON THE THERMOGRAMS

Thermal analysis shows that oxidation influences the plastic properties of coal in the same manner as many of the diluents. Curve 40 which was run to 200° C in air and then in vacuum to 600° C demonstrates the manner in which the carbonization peak deteriorates under the influence of oxygen. Curve 41 reveals that when the sample is run in air the peaks are almost completely destroyed. The sample oxidizes up to approximately 250° C at

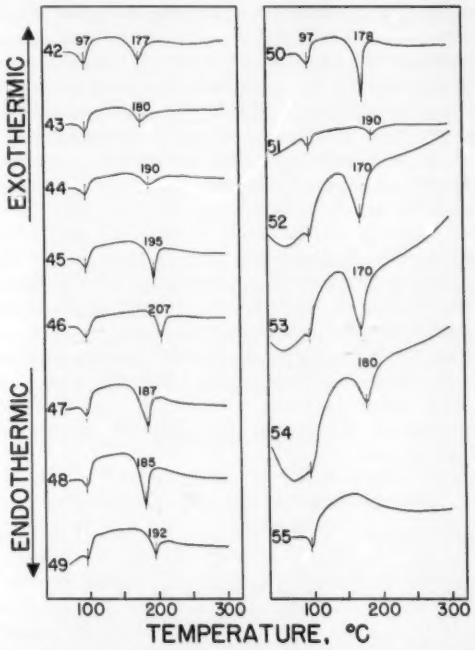

FIG. 7. Thermograms of various rank coals, carbon and graphite all of which have 10% phenanthrene added: 42 (sample 5), 43 (sample 6), 44 (sample 3), 45 (sample 2), 46 (semi-anthracite), 47 (anthracite), 48 (anthracite), 49 (sheared anthracite), 50 (carbon), 51 (graphite), 52 (subbituminous), 53 (subbituminous), 54 (subbituminous), 55 (subbituminous).

which point the primary volatile constituents temporarily prevent further oxidation. As the rate of devolatilization decreases, the curve again bends in the exothermic direction indicating renewal of oxidation.

REACTION OF PHENANTHRENE WITH COAL, CARBON AND GRAPHITE

In Figure 7 the thermograms are for various rank coals, carbon and graphite, all of which have 10 percent phenanthrene added. Three reactions appear on the majority of the thermograms: the melting point of the phenan-

threne at 97° C, an exothermic reaction immediately following the melting point, and a sharp endothermic reaction in the range from 170–207° C. It is well known that phenanthrene is an extremely good solvent for bituminous coal at high temperatures (B.P. 340° C) so it is thought that the reactions might be related to the swelling and dispersion of the coal. Work by Mathieu, Schulz, Calvet, Desmaroux and Petitpas (4) have shown that in many cases macromolecular substances swell in two stages during solution: intramicellar [1] swelling (an exothermic process) and intermicellar [2] swelling (an endothermic process). The thermograms indicate that this might be the case with coal and phenanthrene and that the sharp endothermic reactions between 170–207° C represent the point at which the polycylic aromatic crystallites of the coal are attacked by the phenanthrene. Assuming this explanation to be correct, then the relative heights of the peaks would be a function of the amount of aromatic structure present in the sample, as well as the concentration of the phenanthrene. The concentration of the phenanthrene would depend in part on the amount of interal surface in the sample.

The picture is further complicated by the fact that the solvent action of phenanthrene depends on the rank of the coal and while it disperses bituminous coals readily, it is a relatively poor solvent for lignite and subbituminous coal and very poor for anthracite (7). On these grounds one might expect the bituminous coals to show larger peaks than the low-rank coals and the anthracites but this is generally not the case.

It appears that the above explanation for the reaction of phenanthrene with coal might not be completely satisfactory. Possibly a more comprehensive investigation using other aromatic solvents of high boiling point might clarify these phenomena and further elucidate the present concepts of the colloidal structure of coal.

SUMMARY OF RESULTS AND CONCLUSIONS

The principal conclusion is that differential thermal analysis can be used to study the coking properties of coal. Through correlation with other methods for studying the plastic properties, it is shown that the thermograms reveal most of the well known changes that occur during carbonization such as softening, solidification, etc. In this respect the study reveals nothing new with regard to the fundamental aspects of the coking process.

The exothermic nature of the thermal peaks is in agreement with the rather widely accepted idea that heat is evolved during the carbonization process. It is not known if the exothermic peaks of the thermograms represent heat evolved from the chemical reactions or if they are merely a reflection of the physical changes such as swelling and plasticity which might be made apparent through changes in the heat capacity of the sample. It is believed that less empirical methods must be employed in order to determine whether or not the curves are evoked by heats of chemical reaction, by changes in the heat capacity of the sample or by a combination of the two processes. It is quite probable that the latter explanation is more in accord with the facts.

[1] Intramicellar-reactions occurring between the crystallites.
[2] Intermicellar-reaction occurring inside the crystallites.

No formal attempt has been made to compare the relative merits of the various methods for studying the plasticity of coal. The differential thermal method provides the following information: the softening temperature, the temperature zone of maximum fluidity and maximum swelling, a slight indication of the degree of fluidity, and the solidification temperature. The height of peak No. 1 might also prove to be of value in later studies. The determination of the degree of fluidity is very definitely a weak point in the differential thermal method. On the other hand, an important advantage of this method is that the sample is not weighed down with a probing rod or disturbed by any other type of mechanical device and is thus permitted to swell freely.

It is further concluded that through microscopic examination of the coke samples produced during thermal analysis, an indication of the nature and quality of the coke can be obtained. In order to evaluate fully the possibilities of this method, an extensive investigation must be carried out with the aim of correlating the results with those of a large-scale method, using qualitative descriptions of the coke structure, as well as quantitative measurements on pore size and cell wall thickness as means for comparing the two methods.

Differential thermal analysis is also adaptable to studies on coal with regard to blending, addition of diluents and effects of weathering. The relative influence of various diluents on a given coal can be readily observed and it is believed that such a technique might be useful not only for studies on the improvement of coke but also for fundamental work on the structure of coal and the mechanism of coke formation.

ACKNOWLEDGMENTS

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DEPT. OF GEOLOGY AND GEOPHYSICS,
MASS. INSTITUTE OF TECHNOLOGY,
CAMBRIDGE, MASS.,
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REGIONAL SETTING AND MINERALOGIC FEATURES OF THE HOWELL ZINC PROSPECT, JEFFERSON COUNTY, W. VA.

JOHN C. LUDLUM

ABSTRACT

Renewed exploration of an old zinc prospect in Jefferson County, West Virginia, in 1953 by the United States Bureau of Mines and Tri-State Zinc, Inc., led to a field study, sampling, and a petrographic study of thin sections and polished sections of the samples. Resulting descriptions of the deposit show that it constitutes an additional member locality of the "Appalachian low temperature zinc province," a convenient designation proposed for a series of analagous deposits containing sphalerite in the Valley and Ridge sections of Alabama, Tennessee, Virginia, and Pennsylvania.

The prospect is developed in the Cambrian Tomstown dolomitic limestone near its contact with the underlying Antietam sandstone on the east side of the Great Valley at the base of the Blue Ridge. There is stratigraphic and structural control of the mineralization as it is in steep westward-dipping breccia zones that roughly follow the bedding. Both cavity filling and replacement were methods of deposition from solutions probably rising from magmas during upper Paleozoic time.

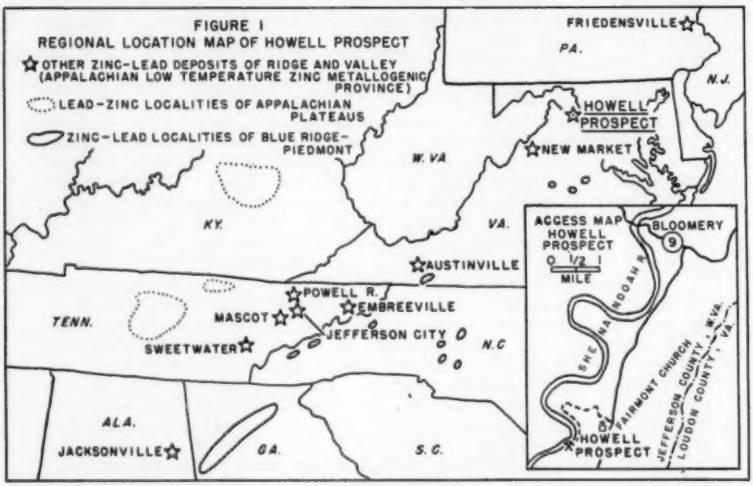
Fine fracture cleavage and persistent feldspar typical in the prospect samples have not been recorded as characteristic of the other deposits of the province. However, rosette or halo zoning of the minerals in several patterns and the assemblage of dolomite, quartz, pyrite, sphalerite, and galena, which are characteristic of the other deposits of the province, are also common at the Howell prospect. The paragenic sequence is (1) pyrite, (2) early white dolomite, (3) feldspar, (4) quartz contemporaneous with a second stage of white dolomite and, in some places, followed by still later white dolomite, (5) sphalerite, (6) galena. The prospect is not large enough or of high enough tenor to be of much commercial promise but its description is merited as it bears on definition of the metallogenic province and also represents the richest hydrothermal base metal deposit recorded in West Virginia.

HISTORY OF DEVELOPMENT

THE Howell zinc prospect (Fig. 1) was known locally and opened to a certain extent perhaps fifty years ago but no record of it has been found in files or publications of the West Virginia Geological Survey. Prospecting was renewed in the spring of 1953 during which the remains of an old shaft were found and also a shallow core hole which was reportedly driven by hand rotary methods. The 1953 prospecting was initiated by personnel of the Mining Development Branch, United States Bureau of Mines, after project priorities made practical a general reconsideration of correspondence in their files relating to possible ore bodies, during which reference to the deposit was noted. As a result of a preliminary field examination confirming some

metallization, and after an arrangement was made with a local land owner, Mr. Ulysses Howell, the Bureau of Mines directed the excavation of one longitudinal and four cross trenches extending through the mantle and into the upper bedrock of the deposit.

Mineralization thus exposed was examined by representatives of a number of mining companies, the United States Geological Survey, and the West Virginia Geological Survey. It was of sufficient promise that Tri-State Zinc, Inc., acquired an option on the property and contracted a limited diamond coring program later in 1953. Results of the coring have not been released, but a spectroscopic analysis by the West Virginia Geological Survey of a sample of the more highly mineralized rock in one trench showed 4.92 percent zinc and a fraction of one percent lead. The low tenor and limited



extent of surface mineralization do not indicate that commercial development will be feasible but the deposit does merit description not only because it is the richest hydrothermal base metal deposit recorded in the state, but also because it serves to direct attention to the number of mineralogically similar deposits in the Appalachian region, particularly in the Valley and Ridge province.

REGIONAL SETTING OF HOWELL PROSPECT

Although lead and zinc deposits are also numerous in the Appalachian Plateaus and in the Blue Ridge-Piedmont areas, those of the Valley and Ridge seem to be most alike and also include those deposits of greater commercial importance to date. They are found in northeastern Alabama; Tennessee, including the Mascot, Jefferson City, and Embreeville commercial deposits; Virginia, including the Austinville commercial deposit;

now in West Virginia, the Howell prospect; and Pennsylvania as represented by the current Friedensville development.

A convenient designation here proposed for the area including these analogous deposits is the "Appalachian low temperature zinc province." The outstanding similarities of the deposits are: (1) the preponderance of sphalerite over galena and the presence of considerable pyrite, (2) the association with intensive dolomitization and to a lesser degree silicification, (3) deposition by cavity filling of brecciated carbonate rocks supplemented by replacement, (4) age of host rocks commonly Cambrian or Ordovician, (5) similar ore forms and textures such as "cockade ore" or "halo mineralization." The ore-bearing solutions are generally considered to have risen or migrated laterally from intrusions of probable Carboniferous age although these are generally not exposed near the deposits.

The general outline of the southeastern part of the province was suggested by a map published by Oder and Hook (1) in 1950. In 1955 Herbert and Young (2) described deposits recently prospected in the vicinity of New Market, Virginia, similar to the other deposits of the province.

LOCAL GEOLOGY

The Howell prospect is developed in the Tomstown dolomitic limestone of Cambrian age near its contact with the underlying Antietam sandstone on the extreme eastern edge of the Great Valley at the base of the anticlinal Blue Ridge. Dips are in some places vertical or slightly overturned but predominantly are 75 to 85 degrees to the northwest. The topography is closely controlled by the structure so that the prospect is near the base of a steep westward-facing slope that also forms the east bank of the Shenandoah River. The river is so close to the Blue Ridge along this part of its course that its flood plain is entirely to the west or on the side of the river opposite to the prospect. Consequently, access to the prospect and rigging of the core drill on successive locations entailed considerable difficulty.

Evidence in the outcrop of indirect stratigraphic control of the mineralization is found in its roughly tabular form parallel to the bedding. The direct control is structural in that dynamic forces have selectively brecciated certain layers or series of beds of the original dolomitic limestone. Of the breccia zones, some were propitiously open at the time of the circulation of the hypogene solutions and these served as sites of deposition. Cavity filling of interstices between breccia fragments was augmented by appreciable replacement of some of the fractured limestone. The degree of brecciation is milder and the scale somewhat smaller than is the rule at Austinville or Mascot-Jefferson City and in terms used in those areas might be described as "fine crackle breccia" rather than "coarse crackle breccia," "rubble breccia," or "founder breccia."

PETROGRAPHIC FEATURES AND PARAGENESIS

Several features of thin sections and polished sections of the mineralized rock from the Howell prospect have not been seen by the writer in studies

of samples from other deposits of the province. Among these are fine structures such as closely spaced fracture cleavage planes that were not open to ore mineralization themselves but helped to determine directions of coarser fractures that were subject to mineralization (Fig. 2). Related to these structures are veins in the axial plane positions of tiny fracture-cleaved folds having wave lengths and amplitudes on the order of 1/4 inch (Fig. 3). Another noteworthy feature is the persistence of feldspar in the Howell prospect samples (Fig. 2).

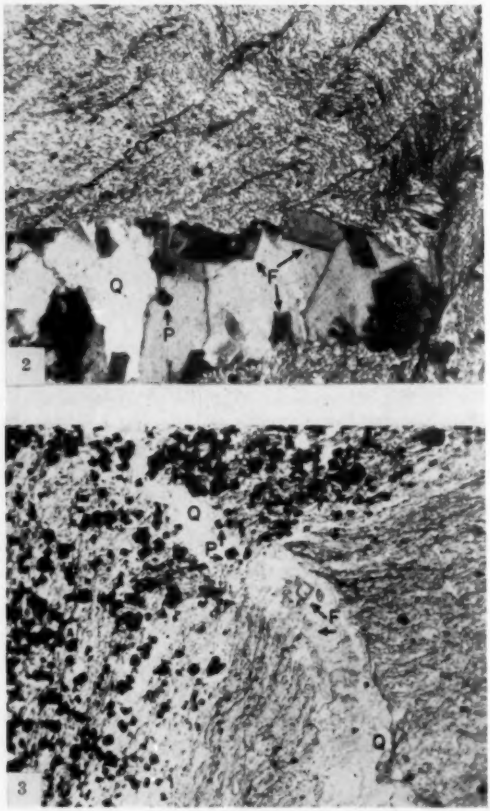


FIG. 2. Fracture cleavage (FC) in unaltered Tomstown dolomitic limestone cut at small angle by quartz (Q) veinlet bordered by coxcomb of feldspar crystals (F). Pyrite (P). Crossed nicols, × 75.

FIG. 3. Quartz (Q) veinlet in axial plane position of minute fold in unaltered Tomstown dolomitic limestone (lower right) and pyritized (P) Tomstown (upper left). Secondary feldspar (F) in quartz veinlet. Ordinary light, × 75.

Rosette, cockade, or halo zoning of minerals, which is characteristic of many of the other deposits of the province, is also common at the Howell prospect. In one pattern a fracture in the original carbonate is lined with a comb structure of feldspar laths extending inward into a zone of quartz (Fig. 2). Galena selectively replaces the quartz in some specimens. Another pattern shows a center of sphalerite around which is an envelope or halo of

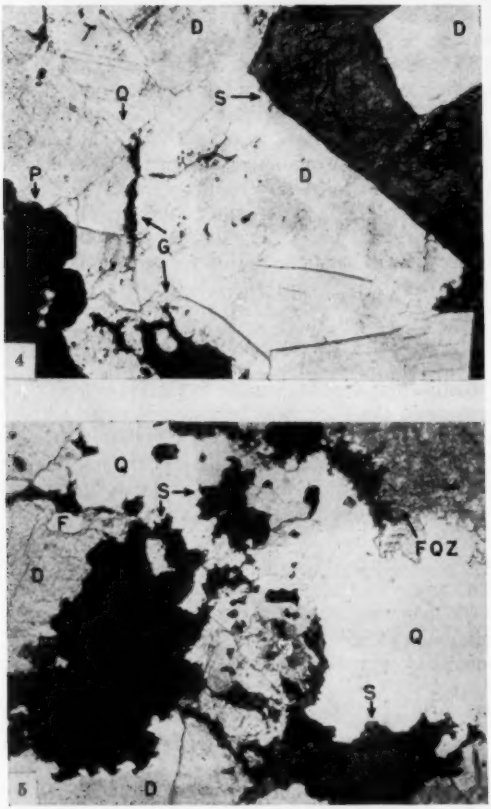


FIG. 4. Section of ore showing sphalerite (S) surrounded by secondary white crystalline dolomite (D) containing galena (G) and quartz (Q). The next zone towards the country rock shows pyrite (P) and then there is a second zone of dolomite not shown. Ordinary light, × 70.

FIG. 5. Section of ore showing contact with original Tomstown dolomitic limestone (extreme upper right), then zone of fine feldspar and quartz (FQZ) and coarser quartz (Q). Zone rich in sphalerite (S) is developed around core of white crystalline dolomite (D). Ordinary light, × 75.

secondary white crystalline dolomite containing galena, then a zone rich in pyrite followed by a second zone of white crystalline dolomite, which in many places is in contact with the fine gray original carbonate (Fig. 4). A third pattern shows a sphalerite-rich zone developed interior to a marginal quartz zone and more or less enveloping a core of white secondary dolomite (Fig. 5).

The order of mineral deposition typical of the Howell samples is: (1) pyrite, (2) early white dolomite, (3) feldspar, (4) quartz contemporaneous with a second stage of white dolomite and, in some places, followed by still later white dolomite, (5) sphalerite, (6) galena. The several stages of deposition of white secondary dolomite might be expected to result from continuous circulation of solutions arising from progressive local replacement of the original dolomitic limestone. Unimportant amounts of late generation pyrite were also observed in the sections. The paragenic sequence is generally similar to that of other deposits in the province that have been described, but differs from some in certain respects. For instance, Herbert and Young (2) in describing the deposits farther south in the Great Valley near New Market, Virginia, placed the galena deposition before the sphalerite and apparently recognized only one period of deposition of secondary white dolomite.

CONCLUSION

It is quite possible that deposits similar to the Howell zinc prospect, which is at present unique in the state, will be found elsewhere in West Virginia. The areas favored by precedent established in other parts of the province will be those of easily fractured and replaced calcitic and dolomitic limestone. Precedent also favors those limestones of Cambrian or Ordovician age, although if the source solutions rose from magmas of Pennsylvanian age, the possibility of there being host rocks among the important limestones (and even sandstones) of Silurian, Devonian, and Mississippian age should not be ruled out. The same rocks would be the most likely sites of metallization even if the source magmas were Triassic or younger because structures and lithologies of the Pennsylvanian and Permian rocks are generally unfavorable, and younger potential host rocks of appreciable extent are not present in West Virginia.

ACKNOWLEDGMENT

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WEST VIRGINIA GEOLOGICAL SURVEY AND
WEST VIRGINIA UNIVERSITY,
MORGANTOWN, WEST VIRGINIA
July 15, 1955

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GEOLOGY OF IMPORTANT HYDRO-ELECTRIC POWER STATIONS OF AUSTRIA

ERHARD M. WINKLER

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ABSTRACT

Geological and some important technical data of interesting power projects of the Austrian Alps and Fore-Alps are discussed. A chapter on general geological problems of dams and reservoirs precedes a general bibliography on the geology of dams of the Eastern Alps.

INTRODUCTION

It is the purpose of this paper to acquaint the American geologist with the success, difficulties, and failures of the construction of some daring hydro-electric power stations of the Austrian Alps.

The disintegration of the Austro-Hungarian Monarchy in 1918 created new political and economic problems in Central Europe. The establishment of tight border lines and strict custom barriers between the small states isolated these small countries; Austria was cut off from Czechoslovakian coal, and Hungary from Austrian industry. Thus, the complete lack of coal in Austria necessitated an emergency program of switching from coal to water power. The steep slopes of the swift Alpine streams and large rivers of the

Fore-Alpine lands were used for the construction of hydro-electric projects. A few large plants had arisen between the end of the First World War and the beginning of the great depression of 1929, with financial help from Italy, Switzerland, France, and Germany. The growing independence of the Austrian power supply led to a decrease in the importation of coal from Czechoslovakia and Poland; they were about to lose one of their best customers. Political manipulations on the part of the coal-producing countries stopped the development of more plants in Austria at that time. However, the outbreak of the Second World War and the total blockade of Germany by the Allies, forced the resumption of the old projects in 1939. The Austrian government continued building water-power projects up to the present time from 1945 on, after a short interruption in 1945, during the general chaos in Europe. The American European Relief Program, by granting sufficient funds, made possible not only a successful extension of already existing plants but also the realization of a number of huge projects that have made Austria one of the leading countries in the production of hydro-electric power. The electrification of the Austrian Federal Railways, which had been abandoned in 1929, has now been successfully carried out. There is such a surplus of electricity today that a large part can be exported to France, Italy, and into the industrial centers of Western Germany, partly as repayments for financial help.

HISTORY OF THE PLANNING AND THE CONSTRUCTION OF THE PLANTS SINCE THE FIRST WORLD WAR

Because Austria covers the entire area of the Eastern Alps (Fig. 1), it has an abundance of mountain streams with steep gradients; they flow through former glacial lake basins high up in the mountains, through glaciated valleys, and through wide basins of flat, fertile land, and farther down towards the plains they traverse narrow, erosional valleys. The lack of water during the winter months has to be balanced by large reservoirs. The water is carried by open flumes, free-flow water tunnels, or water pressure tunnels from the reservoir to the surge tank near the power house, and then by pressure pipes or penstocks down to the turbines in the power house; the penstocks may be built underground or on the surface. The difference of the water level between the surge tank and the power house gives the necessary pressure to the turbines, the power drop. Under favorable circumstances a whole system of stations above and behind each other may arise, as is found along the rivers Ill, Enns, Drau, and Kamp. The hydrological conditions favored the construction of high pressure stations; their prior success in France, Norway, and Switzerland encouraged some daring projects in the Alps. With the development of larger and higher constructions problems of seepage, of reliable foundations, and of rock pressures in the tunnels had to be considered very carefully. More and more the expert opinion of a well trained geologist became indispensable. Rather than abandoning a site for a project because of complicated geologic conditions, today the aim is preferably the choice of proper construction methods to fit the geologic circumstances. Moreover, the civil engineer has developed a number of types of dams, which allow the

geologist to take advantage of any valley cross-section and any quality of rocks today. Professor Stini of Vienna realized these facts at an early stage of dam development and many of his ideas have been published in various Austrian journals.

The evolution of the dam design in Austria since the First World War shows the tendency of higher dams with an increasing size of the reservoirs. Arch dams and multiple arch dams had been used successfully for some time in the United States of America, France, and Italy, in narrow canyons with good banks as solid abutments. The arch dam was first introduced in Austria 1943 with the construction of the Gerlos dam (A-6).[1] Stini recommended gravity dams for wide valley cross-sections, arched dams for narrow canyons with sound banks, and rolled earth or stone fill dams if neither of the other types was feasible (34).[2]

HYDRO-ELECTRIC PLANTS AND THEIR GEOLOGIC PROBLEMS

Selection of the Kind of Dam for the Alps

Reservoirs in Glacial Troughs.—The valleys of the high Alps are mostly glaciated; numerous glacial troughs now generally filled with post-glacial lake sediments commonly offer a fresh bedrock surface of the glaciated basins, especially at their downstream end. Filled-in post-glacial lake basins with a solid rock bar at their end were encountered at the three reservoirs of the Tauern project (A-23) and Tauernmoos (A-22). With the Achensee (A-1) the natural lake still fills the basin, thus no dam was necessary and the control work for the intake could be placed directly into the rock bar. The conditions are similar with the Spullersee (A-20); however, two dams close the valley and raise the water table, one with the Plansee (A-15). Cirques are similar in their formation to glacial troughs, but much smaller in size. A number of cirque lakes will supply part of the water for the Reisseck power system (A-17) with a total difference of elevation of 1,700 m, which height will make up for the scant water supply of the reservoirs. Additional water from several streams on the other side of the divide has to be added by transfer tunnels.

The lowering of the water level of some natural lakes, necessary during the time of construction, has caused considerable slumping both of the lake banks (A-1) and of the sloping post-glacial lake sediments of the Spullersee (A-20) and the Strubklamm (A-21-a).

Dam Foundations.—The natural formation of both the bed rock and topography influences greatly the choice of the foundation to be used in dam construction. Youthful erosional valleys with steep slopes generally expose the bedrock on the surface or covered only with a thin mantle of gravel. On the other hand, older topography is characterized by more gentle slopes and a much thicker mantle. Later rejuvenation of an area brings about topographic breaks of the valley slope (A-24). Erosion has commonly taken place along heavily jointed areas and weakened zones, giving rise to subsequent valleys (Danube at Ybbs B-17, B-1). Major shear zones were encountered outside

[1] A-6, B-10, etc. refer to number of dams given in Appendix.
[2] Refers to Annotated Bibliography.

of both the wings of the Langmann dam (A-24-b); the dam itself, however, was founded on solid gneiss. Profound shearing of one of the wings of the Hierzmann dam (A-24-a) was successfully grouted. Grouting of sheared gneiss at the right abutment of the arched dam at Dobra (B-1) was less successful, where surface waters poured through the weak zones into the upper part of the tunnel near the dam in the winter of 1954–55, despite careful excavation and grouting in the winter of 1953–54.

The stability of the dam as well as the water proofness of the reservoir is highly influenced by the strike and dip of the strata. Excellent conditions are experienced with strata striking at right angles to the valley and dipping steeply downhill, as is demonstrated at Langmann (A-24-a) and Frain (B-3). The two dams of the Spullersee (A-20) stand on Jurassic marls that strike parallel to the axis of the dams, and dip vertically; thus they stand as on sheet piles.

High structures on uncemented soil have been avoided as yet. However, an earth rolled dam of 100 m height was once planned in the middle Oetz valley in the Laengenfeld Basin, on the alluvial sediments of an old lake

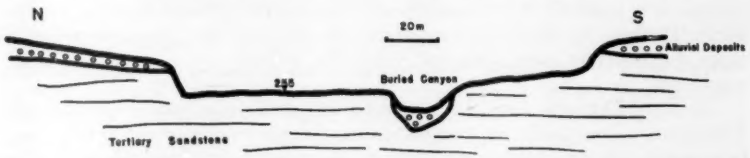

FIG. 2. Cross-section through the buried channel of the Drau river at the power station Marburg (B-10) (reproduced from: Stini, J., Zur Kenntnis der Tiefenfurchen, Geologie und Bauwesen, 1946–48, p. 96–105).

trough (80 m sand and silt); there, possible irregular settlement would not have been too critical for the dam as planned. Sheet piling, however, would have had to reach the bedrock surface in order to seal the reservoir.

Buried Channels.—Another problem involves buried channels that are common along ordinary erosional stream valleys; they are mostly well hidden and cannot easily be detected before the full excavation of the channel is completed. For example, the construction of the dams on the Drau River, near Marburg, and at the Stuibenbach, a tributary of the lower Oetz River in Tirol, quite unexpectedly opened up a narrow deep channel, filled with loose sediments on the bottom of the valley (Fig. 2) (B-10, 37). The "inner gorge" of the Drau River is 30–35 m wide and more than 25 m deep terminated by vertical walls continuing upstream into the State of Carinthia. The gorge of the Stuibenbach, although 28 m deep, is only a few meters wide; consequently test drillings in the valley had missed the gorge entirely. In both cases the expense of cleaning the gorges have greatly increased the cost of the project. The construction of the Stuibenbach was discontinued but might later be resumed.

Channels of glacial origin were encountered at the north dam of the Spullersee (A-20), the Mooser dam, and the Limberg dam of the Tauern

project (A-23-b, c). These cases of glacial trenching seem to be due to glacial plucking rather than abrasion.

Reservoir Leakage and Silting

Seepage Through Glacial and Fluvial Sediments.—Seepage through water-permeable sediments beneath a dam or around a dam is rare, since careful grouting or thorough sheet piling can prevent the loss of water. Grave difficulties, however, have been encountered with a small concrete dam at Pernegg (B-12); the left wing is founded on gneiss and the right on the lower gravel terrace of a set of post-Pleistocene terraces. Here seepage increased so much within a short time, that it soon exceeded a hundred liters per second; the silt and fine sand were gradually washed out from the gravel terrace. The numerous channels formed this way were then closed by loading the right bank with heavy blocks and the installment of a Terzaghi filter. The subsequent consolidation of the sediments in the terrace was so successful that leakage stopped entirely. Good results have been observed with one of the two dams holding the Silvretta reservoir, the Bieler dam (A-9-a); the dam under discussion is a stone-fill dam, founded on a compacted ground moraine on the Bieler Hoehe (the divide that separates the Ill from the Patznaun valley); since the concrete core does not reach the bedrock seepage has been insignificant.

Seepage Through Limestone.—Carbonate rocks may cause considerable difficulties. Pure limestone in a mature or old-age topography generally contains many solution channels that permit loss of water from the reservoir. In many cases the filling of these channels with concrete by grouting has not always proved to be economical. However, incipient formation of solution channels can be successfully countered with proper grouting. In the case of sealing one of the channels at Limberg (A-23-c) the use of excessively high pressures in grouting the channeled marble close to the dam, squeezed out fillings of residual clay from the bottle necks of the channels; thus the tube of the channel was extended to a previously sealed adjacent channel and the filling of the whole length of the tube became necessary. By way of contrast, the highly soluble Triassic limestone (Dachsteinkalk) at the Salza dam (A-19) does not disclose any solution channels near the dam; there, a fairly recent uplift of the Grimming Massive, and the resulting rejuvenation of the Salza Canyon, has prevented the relatively slow advance of solution down to the site. Experiments, carried on with salt, showed that springs below the site were not influenced by the waters of the Salza river; the reservoir is entirely tight. On the other hand at the Ternberg Station on the Enns river (B-16) seepage set in at the left wing of the dam. Thorough additional grouting a few years after the completion of the project did not improve the seepage of about 300 liters per second. Grouting apparently missed a channel that had been formed by the solution of gypsum in Triassic dolomites; the seepage is increasing every year but is not critical as yet.

Water may move also through open joints, faults, and shear zones beneath the dam. Thus, considerable loss of water may result. If the water-

permeable shear zones cross over into a parallel neighboring valley, water from the reservoir may be carried over as through a system of syphons. Trouble of this kind was feared with some big projects in the Central Alps (A-23, A-22). In general early careful grouting prevents seepage.

Filling of the Reservoir. The preservation and life of a reservoir may be affected by the permanent filling with mud, silt, sand, and gravel. Although most of the Alpine reservoirs do not seem to be in immediate danger of becoming filled, smaller reservoirs along the Mur and Drau rivers, however, were already filled after twenty years of operation. The small reservoir at Pernegg (B-12) and Laufnitzdorf on the Mur river had to be flushed out for a week in the years 1938 and 1946, and were back in use afterwards. The reservoir at Faal on the Drau (B-2) had to be abandoned entirely; the sedimentation at Faal amounted to 1,520,000 m^3 between 1918 and 1920. Sedimentation was measured at the Tauernmoos reservoir (A-22) holding 22 Mill m^3, with 11,000 m^3 mud and 17,000 m^3 sand a year; hence the process of sedimentation may be completed in 800 years.

Pressure Tunnels, Surge Tanks, and Penstocks

The disturbance of the equilibrium of rock formations by excavations of tunnels, subsurface penstocks, and surge tanks frequently brings about closure by rock pressure. Good quality rock withstands both the overload pressure and tectonic rock pressure. Thick overburden may cause deformation of the rocks and squeezing into the tunnel. The Moell transfer tunnel of the Tauernkraftwerk (A-22-a) may be quoted as an excellent example; it cuts through hard, solid, marble schist that showed no effect of rock pressure at 400 m below the surface, some effect between 400 and 800 m depth, and constant pressure at greater than 800 m depth. In tunnels close to a surface slope there frequently occurs some squeezing due to the outer layers creeping down the slope (rock creep), a contribution to the eventual filling of the valleys. Pressures of this origin were especially great in the Gerlos pressure tunnel at km 1.1 to 1.8 (A-6). Here the coincidence of the strike of the tunnel axis with the strike of the vertically dipping sericite schists, plus numerous springs close to the contact of the schists and limestone, forced the engineers to detour the tunnel into dry, resistant limestone. Tunnels that cross crushed zones and faults usually require heavy timber lining and measures against flooding. Moreover, surface precipitation may penetrate along shear zones down into the tunnel (A-9-c). Experiments on rock pressure in the water tunnel of the Spullersee (A-20) resulted in cracking the rock with considerable seepage of water from the tunnel into the mountain, at an inner pressure of only 2 to 4 atmospheres; thus the tunnel was unsuitable for the use as a pressure tunnel. Cracked dolomite in and near the surge tank of the same station had to be grouted and lined with heavy concrete to prevent collapse. At Braz (A-3) severe rock pressure developed at the contact of the Northern Limestone Alps with the Graywacke zone (Fig. 3), which amounted to as much as 300 tons per meter. At Ruetz (A-17) and Obervellach (Mallnitz A-11) morainal clays and quicksands of glacial outwash, interbedded with

the moraines, caused strong pressure by the swelling of the clays. Despite thorough lining of the tunnel at Ruetz, part of it had to be abandoned for an open air conduit.

Sulfate Rocks in Tunnels.—The presence of beds of gypsum and the sulfate waters resulting from this mineral can cause destruction of the Portland cement used to line the tunnels. Minor concentration of sulfate waters may be derived from the decomposition of pyrite, as has been found frequently in the mineralized Graywacke zone. Kastner (9) discusses a number of cases of failures of tunnel linings made with Portland cement in zones of SO_3 waters, and concludes that less than 100 mg of SO_3 per liter are of no danger, quantities of 100–300 mg SO_3 per liter require the application of high alumina cement, 300–500 mg per liter require the best cement available and careful drainage of the sulfate waters, and areas with more than 500 mg of SO_3 per liter should be avoided.

The first experience of failure of a cement lining in Austria occurred at Opponitz (A-12) where the free-flow water tunnel intersected 2,300 m of gypsiferous shales of the Triassic Opponitz formation. Here insufficient inclination of the tunnel axis (0.85%) caused seepage of the sulfate waters into the tunnel lining, composed originally of concrete stone masonry of Portland cement with asphalt mortar and ground drainage of clay pipes. The lining was completely destroyed and had to be replaced by concrete rings of high alumina cement in 1926, within the gypsiferous section of the tunnel. The operation was successful since, except for a solution cavity beneath the floor of the tunnel, which developed early in 1930.

The 5,984 m tunnel at the Gerlos dam (A-6) is partly located in solid quartz-phyllites of the Graywacke zone; the central part, however, is in soft sericite schists that are infiltrated with stringers of crystalline gypsum. The numerous springs and dripping water within this zone exceed 400 mg SO_3 per liter of water. Although the crystals were easy to find J. Stini developed a rapid semi-quantitative field test for sulfuric acid based on the visual intensity of precipitation of white milky barium sulfate from powdered barium chloride in a test tube in the tunnel (31). Special high-alumina melting cement was used along a stretch of nearly 1 km and the proper ground drainage of the sulfate waters was provided. Just a few years after completion of this project huge blocks of concrete twice crashed down through the pressure shaft into the power house in August 1945 and 1947. Neuhauser [3] ascribed the catastrophe to a coincidence of unfortunate circumstances, e.g. poor war quality of the special cement in connection with apparently insufficient drainage of the sulfate waters, unusually high rock pressure in the upper part of the pressure shaft, poor quality of the steel pressure pipes, etc. No further damage has been recorded since.

The presence of gypsum was found in the tunnels of a number of other power plants but early detection of the nature of the waters and the proper application of the necessary measures guaranteed good operation of the following stations up to present date:

[3] Neuhauser, E., Die Ursache der Rohrbrueche im Druckschacht des Gerloskraftwerkes. Oesterreichische Wasserwirtschaft, 1950, p. 185–211.

1) Achensee (A-1)—some sulfate waters from Neocomian shales with 487 mg SO_3 per liter; high-alumina cement and proper ground drainage prevented damage.

2) Braz (A-3)—some gypsum in the transitional zone of the Northern Limestone Alps to the Graywacke zone; high-alumina cement with trass (volcanic slag) as aggregate sealed the tunnel.

3) Kitzlochklamm (A-10)—315 m tunnel section in gypsiferous talc and chlorite schist of the Graywacke zone; some damage of the concrete was detected in 1930 from waters carrying 465 mg SO_3 per liter. Successful operation after the repair since.

Rock pressure due to hydration of anhydrite into gypsum could not be observed in the Alps; here the anhydrite, if present, mostly occurs in veinlets that leaves sufficient space for possible expansion of the mineral.

Power Houses

Power houses with one or more sets of turbines are generally located at the lowest point of the area to achieve the highest possible head of water. The flood plain of the main valley close to the mountain slopes is the most common foundation. The very high revolutions of the turbines require solid foundations to diminish vibrations and prevent uneven settlement. Layers of peat between sand and gravel may cause irregular settlement of the power house if the organic layer is located close to the surface (A-6). Any moraine as a foundation for a power house should be investigated very carefully for the possibility of slumping, although it may prove to be quite satisfactory, as at the Tauern project (A-23-c). Snow and rock avalanches are a permanent threat to the foot of a steep slope. The power house may be placed in the mountain side if the stability of the rock permits. Underground power houses were built in Austria at the Achensee (A-1), Partenstein (A-14), and Braz (A-3).

CONSERVATION OF LAND AND SCENERY

The development of the size and shapes of dams has been great since the First World War. Today canyons are interrupted with constructions that follow and match the curves of the landforms, damming up a beautiful mountain lake. The proper construction of dams, their adjustment and coordination to nature is a very important task for the engineer, hence most of those stations are located in areas that display the beauty of part of the High- and Fore-Alps. Intermountain glacial basins, previously filled with muck, swamps and rock debris, offer a different view if filled with clear deep blue or green water. Glaciers in the vicinity improve the marvelous play of colors and contrasts. Lakes along a river in hilly topography promote the establishment of new recreational areas and fishing sites.

The design of power houses has likewise become more progressive; smaller constructions are sometimes built like neat farm houses in the style of the local region (A-18). Larger power houses for requirements as at Kaprun (A-23-c) and Reisseck (A-17) are lower in height with hidden transformers if possible. The placement of such a station underground solves the problem

of architectural adjustment. Low pressure river plants have also improved their designs. Huge, ugly gallow-like bridges and derricks such as were built at Faal (B-2) and the high red bridge of the Kachlet Danube plant in Bavaria are now replaced by low, scarcely visible constructions with modern plants. Low buttressed dams with the total overflow of the dam between the buttresses are the modern trend, as seen at Schwabeck (B-16) or as planned at Ybbs-Persenbeug (B-17). Arno Fischer built dams in Southern Bavaria with the dam entirely overflown; such underwater stations do not exist in Austria as yet.

Equally important is the question of land conservation. The scarce and densely populated farmland in the Alps is mostly restricted to the lowlands and intermountain basins, which at the same time offer a perfect site for a reservoir. Thus, the resistance of the population that has been attached to those places for many centuries may be so strong that, for instance, plans for a huge reservoir at the Laengenfeld Basin in the upper Oetz Valley had to be abandoned. Compensation for flooded fields and villages was arranged at great expense at Grossraming (B-5) where modern homes were offered by the government in exchange for obsolete buildings.

In the following appendix, a list of the important power plants of Austria gives important technical data; most of these plants have already been mentioned in connection with the geological problems. High pressure stations carry the letter A before the number; low pressure stations (river plants) are denoted by B. The location of both groups is marked on the hydrological map of Austria.

ACKNOWLEDGMENTS

Special thanks are due to Professor Joseph Stini, Vienna, who has been a permanent consultant with most of the hydro-electric power plants in Austria for many years; he gave me much information and encouraged me to write this paper. Critical suggestions and more information were achieved from Professor Steponas Kolupaila, University of Notre Dame, Dr. Werner Kresser, Vienna, and Dr. Georg Horninger, Kaprun. The manuscript was read by Professor Stini, Vienna, and Dr. Charles Parnell, Department of Modern Languages, Notre Dame, Indiana.

UNIVERSITY OF NOTRE DAME,
NOTRE DAME, INDIANA,
June 1, 1955

APPENDIX A.

Key to the abbreviations for the list of power plants:

Gr—granite	Qu—quartzite	g.—gravity dam
Gn—gneiss	C—conglomerate	a.g.—arched gravity dam
Amph—amphibolite	Sh—shale	b.g.—buttressed gravity dam
Ph—phyllite	Ls—limestone	a.—arched dam
Sch—schist	D—dolomite	a.a.—double arched dam
M. Sch—marble schist	G—gypsum	e.—earth dam
		c.—low control work

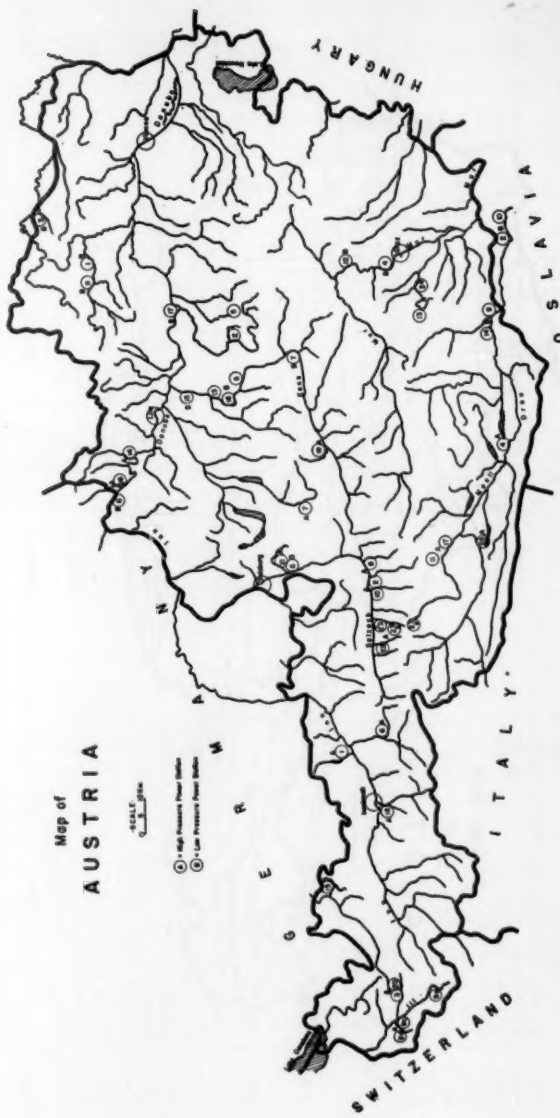

FIG. 1. Map of Austria. (Upper figure "2" should read "12.")

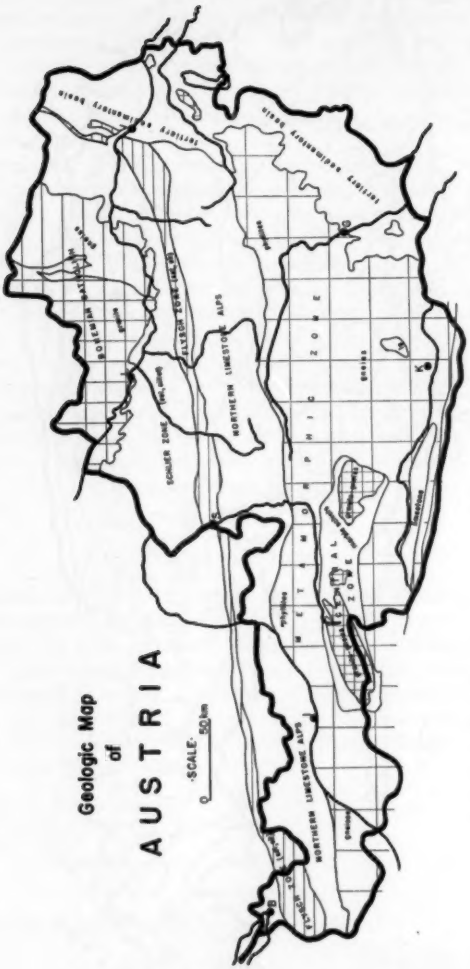
Geologic Map
of
AUSTRIA
SCALE: 50 km
BOHEMIAN MASSIF
MOLDANUBIAN
MOLASSE ZONE
FLYSCH ZONE
NORTHERN LIMESTONE ALPS
METAMORPHIC ZONE
CRYSTALLINE ZONE
GRANITE
GNEISS
SCHISTS
PERMIAN
TRIASSIC
JURASSIC
CRETACEOUS
TERTIARY
QUATERNARY

FIG. 3.

Number	Name of plant	Source of water	Reservoir	Type and height of dam	Rock	Power drop	KW	Finished
A-1	Achensee	Achensee	36 Mill	no dam	Ls, G	380 m	93,000	1927
A-2	Arthurwerk	small stream	no res.	c.	Ph	195 m	2,800	1928
A-3	Braz	Alfenz	no res.	c.	Ph, D, G	305 m	36,600	1953
A-4	Forstsee	small stream	3.89 Mill	e, 7.5 m	Ph, Sch	157 m	5,300	1925
A-5	Gaming	Erlauf	no res.	c.	Ss, Sh, D	188 m	4,200	1926
A-6	Gerlos	Gerlos	0.877 Mill	a. 39 m	Ph, Qu, G	600 m	57,000	1944
A-7	Gosau system:							
	a) Upper step	Gosau Lake	11.5 Mill	e, 16 m	moraine	125 m	7,460	1914
	b) Middle step	Gosau	3 Mill	g. 30 m	Ls, C	15 m	1,120	1929
	c) Lower step	Gosau	1.3 Mill	c.	Ls, D	190 m	13,700	1911
A-8	Grossarl system:							
	a) Upper step	Arl	—	c.	moraine	95 m	2,240	1935
	b) Lower step	Arl	—	c.	Ph	156 m	3,500	1935
A-9	Ill River system:							
	a) Silvretta	Ill	38 Mill	g. 80 m 3. 34 m	Gn moraine	247 m	30,000	1943
	b) Vermunt	Ill	5.3 Mill	g. 57 m	Gn	688 m	117,000	1928
	c) Rodund	Ill	0.9 Mill	c.	D	339 m	180,000	1949
	d) Luenersee	Luenersee	40 Mill	c.	D	978 m	under constr.	
A-10	Kitzlochklamm	small stream	—	c.	Sch, G	125 m	4,500	1904, 53
A-11	Mallnitz	Mallnitzbach	—	c.	Ph, Gn	323 m	13,000	1926, 53
A-12	Opponitz	Ybbs	—	c.	D, G	115 m	11,200	1924
A-13	P[illegible]k	Packerbach	5.6 Mill	g. 35 m	Gn	245 m	20,000	1931
A-14	Partenstein	Muehl	0.87 Mill	g. 31 m	Gr	170 m	11,000	1924
A-15	Plansee	Plansee	16.4 Mill	c.	D	108 m	6,000	1927
A-16	Rannawerk	Ranna	2.35 Mill	a. 53 m	Gr	?	8,500	1923, 53
A-17	Reisseck-Kreuzeck system; figures for the total project:							
	Gr. Muehldorf	Lake and others	7.9 Mill	c. 47 m	Gn	1,700 m	132,000	u. const.
A-18	Ruetzwerk	Sill	—	c.	Ph, Mor	174 m	6,000	1912
A-19	Salzawerk	Salza	10.5 Mill	a. 50 m	Ls	170 m	6,000	1951
A-20	Spullerseewerk	Spullersee	12.09 Mill	a.g. 37 m a.g. 27 m	D D	800 m	18,000	1925

Number	Name of plant	Source of water	Reservoir	Type and height of dam	Rock	Power drop	KW	Finished
A-21	Strubklamm system							
	a) Strubklamm	Almbach	2.5 Mill	a.g. 36.5 m	D	105 m	8,000	1925
	b) Wiestal	Almbach	6.5 Mill	a.g. 34.5 m	D	85.3 m	4,000	1913
A-22	Stubach system:							
	a) Weiss-See	Weiss-See	?	c.	Gn	200 m	planned	
	b) Tauernmoos	Stubache	22 Mill	g. 30 m	Gn	520 m	24,000	1929
	c) Third step planned.							
A-23	Tauernkraftwerk system:							
	a) Margaritzen	Moell	3 Mill	a. 92 m	M. Sch	water transfer 1952		
				a.g. 40 m	M. Sch			
	b) Mooserboden	Kapruner Ache	86 Mill	a.g. 100 m	M. Sch	361 m	112,000	u.c.
				a. 110 m	M. Sch.			
	c) Wasserfallboden	Kapruner Ache	86 Mill	a. 126 m	M. Sch	890 m	220,000	1951
A-24	Teigitsch system:							
	a) Hierzmann	Teigitschbach	0.74 Mill	a. 58m	Gn	80 m	9,700	1951
	b) Langmann	Teigitschbach	0.3 Mill	g. 26 m	Gn	235 m	22,000	1925
A-25	Wiederschwing	Weissenbach	0.135 Mill	aa. 30 m	Ph	?	9,000	1951
B-1	Dobra	Kamp	19.7 Mill	a. 52 m	Gn	66 m	17,000	1953
B-2	Faal	Drau	res. filled	g. 13.3 m	Gn	12 m	27,500	1919
B-3	Frain	Thaya	160 Mill	g. 55 m	Gn	40 m	4,500	1931
B-3	Gratwein	Mur	small	c. 8 m	mor	7 m	4,000	1926
B-5	Grossraming	Enns	6 Mill	g. 24 m	D	24 m	54,000	1919
B-6	Hallein	Salzach	—	c.	gravel	flood control		1929
B-7	Hieflau	Enns	?	g. 15 m	gravel	85 m	20,000	u.c.
B-8	Jochenstein	Donau	—	g. 11.5 m	Gn	11 m	140,000	u.c.
B-9	Lavamuend	Drau	—	b.g. 9.0 m	Ph	9 m	27,000	1944
B-10	Marburg	Drau	—	b.g.	Sst		50,000	1943
B-11	Ottenstein	Kamp	73 Mill	a. 65 m	Gr	52 m	30,000	u.c.
B-12	Pernegg	Mur	0.5 Mill	c.	Amph	16 m	18,000	1928
B-13	Rosenau	Enns	0.85 Mill	g. 14 m	Sst	14 m	26,600	1954
B-14	Schwabeck	Drau	small	b.g. 22 m	Ph	22 m	60,000	1943
B-15	Staning	Enns	small	g.	Sh	?	33,000	1945
B-16	Ternberg	Enns	5 Mill	g. 15.5 m	D, G	14 m	30,000	1949
B-17	Ybbs-Persenbeug	Danube	small	b.g. 9.35 m	Gr		153,000	u.c.

Appendix B

ANNOTATED BIBLIOGRAPHY ON THE GEOLOGY OF DAM SITES UNTIL 1954

1. Ampferer, O., Geologische Bemerkungen zum Druckstollenproblem. (Geologic notes on the problem of pressure shafts.) Zeitschrift des oesterreichischen Ingenieur- und Architekten Vereines, 1923, p. 283–285. *Weakening of the rock structure due to careless blasting resulting in danger of rock pressure.*
2. Ampferer, O., Geologische Probleme des Baues und der Erhaltung von Talsperren. (Geologic problems of the construction and maintenance of dams.) Die Wasserwirtschaft, 1933, No. 17–19. *General relationship between landforms and rock structures, to dams and reservoirs.*
3. Ascher, H., Erfahrung bei der Fundierung von Staumauern im Hochgebirge. (Experience with the foundation of dams in high mountains.) Wasserkraft und Wasserwirtschaft, 1929, p. 315–319. *Careful blasting and cleaning of rock required as well as detailed geologic investigation of the exposed foundations.*
4. Ascher, H., Beitraege zur Frage der Gruendung von Sperrmauern. (Contribution to the foundation of dams.) Wasserkraft und Wasserwirtschaft, 1939, No. 3–4. *Discussion on proper excavation of foundations, careful grouting, especially with high pressures, and wise supervision by a geologist during the construction.*
5. Bistritschan, K., Flussbaugeologische Karte der Enns. (Hydrologic-geologic map of the Enns river.) Geologie und Bauwesen, 1951, p. 1–8; 1952, p. 29–30. *The geologic interpretation of the sediments of the river, its glacial valley trains and post-glacial river terraces and the morphology of the bedrock floor.*
6. Cornelius, H. P., Ueber einige zu wenig beachtete Gefahren fuer den Bau von Wasserkraftanlagen in den Alpen. (About some insufficiently observed dangers in the construction of hydro-electric plants in the Alps.) Deutsche Wasserwirtschaft, 1941, p. 386–388. *Discussion of crustal movements, rock structures, avalanches, etc., as a danger for dams.*
7. Fill, R., Kluftmessung und Talsperrenlage. (Measuring of joints and the location of dam sites.) Geologie und Bauwesen, 1950, p. 114–125. *Demonstrates methods of measuring jointing of rocks as they were performed at the Hierzman dam. The orientation of the dam to jointing determines the most favorable location.*
8. Haertel, O., Wasserkraftnutzung und Wildbachwesen. (The use of water power and the flood waters.) Oesterreichische Wasserwirtschaft, 1952, p. 155–158. *On the influence of the bed load and avalanches on reservoirs and power houses.*
9. Kastner, H., Die Gefaehrdung von Stollenbauten durch sulfathaltige Bergwaesser. (Danger for tunneling through sulfate waters.) Oesterreichische Bauzeitschrift, 1947, p. 41–48. *Discussion of chemical effects on concrete; special reference is made to difficulties in tunneling through the attack of concrete by sulfate waters (Lend, Opponitz, etc.). Experience shows that there is no danger up to a content of 100 mg SO_3/liter water; the use of special high alumina cements is required with contents of 100–300 mg of SO_3/liter water, the use of the best quality cements and sealing out of the sulfate waters with 300–500 mg SO_3/liter, and avoid or detour the tunnel with more than 500 mg SO_3.*
10. Knop, E., Der Einfluss des Baugrundes auf die Verformung und die Standsicherheit von Staumauern. (The influence of the foundation on the deformation and the stability of dams.) Deutsche Wasserwirtschaft, 1949/50, p. 160. *Model experiments were performed to demonstrate the process of shearing off, rolling, and overturning of dams. The most dangerous form of movement is a combination of all three. Volcanic rocks generally offer a solid base.*
11. Mattern, E., Ueber die Gefahr der Versandung, der Verschotterung, der Bergstuerze oder Gletscherrutsche fuer den Bestand von Staubecken und die Sicherung der Sperrmauern. (On the danger of silting, gravelling and avalanches in the maintenance of reservoirs and securing of the dams.) Wasserwirtschaft und Technik, 1936, p. 247–248. *Due to the lack of experience with high Alpine reservoirs the discussion limits to Fore-Alpine areas, e.g. Faal, Stubach, etc.*
12. Pollack, V., Technisch geologische Bemerkungen fuer Anlage und Bau der Wasserkraftwerke. (Engineering geological notes on the design and construction of water power plants.) Zeitschrift des oesterreichischen Ingenieur- und Architekten Verbandes, 1925, p. 3–7; 1926, p. 160–163, 180–183, 200–203. *The best design to match the most favorable selection of the site and the construction of both wings and foundations; the influence of rock structure and the density of the mountain; also a discussion of slumping of the banks of the Lake Ritom and Lake Davos in Switzerland.*
13. Richter, H., Der Ausbau der Wasserkraefte in seinen Auswirkungen auf die Wildbachverbauung. (The development of the water power with its effect on flood water control.)

Oesterreichische Wasserwirtschaft, 1952, p. 215–221. *Measures against destructive flood waters: a) prevent erosion and corrosion; b) eliminate sources of waste and develop plant cover abundantly; c) grow mixed forest to retard the surface run-off. Torrential waters should pass over control work for the retainment of gravel (Tirolerwehr) before their use for hydro-electric power.*

14. Rosenberg, P., Geologie und Wasserkrafttechnik in Oesterreich. (Geology and water power technique in Austria. Die Wasserwirtschaft, 1923, p. 14–15. *Discussion of the problems of supervision of a project by a geologist during construction, e.g.: silting of the reservoir, movement of the bedrock in pressure tunnels and water seepage; in addition, consideration of the Spullerseewerk, Mallnitzwerk and Partenstein.*
15. Schaffernak, F., Die Wirkungen des Ausbaues von Grosswasserkraftanlagen auf das Flussregime. (The effect of the development of large water power stations on the morphology of the rivers.) Die Wasserwirtschaft, 1924, p. 259–263. *Disturbance of the morphology of rivers by the withdrawal of water by the following causes: a. narrowing, widening, or elevating of the stream beds; b. withdrawal of water from the main channel to the power house; c. equality of year-round water supply by interlocation of a reservoir; d. retaining of the gravel load through silting basins (reservoirs).*
16. Seelmaier, H., Ueber die Baugrunduntersuchung an Flusskraftwerken. (On the investigation of the subsurface in connection with stream power plants.) Geologie und Bauwesen, 1950, p. 9–17. *Investigations of the permeability of reservoirs by core drilling and electric resistivity measurements of a future reservoir as exemplified by the Save valley project.*
17. Stiny, J., Ueber die Anschaetzung der Lage des Felsuntergrundes beim Planen von Wasserkraftanlagen. (About the estimation of the surface of the bedrock at the planning of water power stations.) Die Wasserwirtschaft, 1923, p. 25–27. *Meander scars often disclose fresh bedrock, but in places they may be covered with land-slide material. At the transition of the straight river bed to the bend, the attack of the banks is especially great. Young topography and hard rocks mostly carry a shallow mantle and display hindered growth of the trees.*
18. Stiny, J., Ueber die Lage des Felsuntergrundes bei Talsperrengruendungen. (About the location of the bedrock surface in foundations of water power stations.) Die Wasserwirtschaft, 1923, p. 153–157. *Discussion of the possible position of the bedrock surface as encountered in a stream bed.*
19. Stiny, J., Wasserkraftnutzung und Schlammfuehrung der Gewaesser. (The use of streams for water power and the question of discharge of mud of the streams.) Die Wasserwirtschaft, 1923, p. 152–153, 169–171. *Calculation of the transportation of silt and mud by the Mur river; it depends on the barreness of the land and on the geologic condition of the drainage area.*
20. Stiny, J., Untersuchungen ueber die Wasserdurchlaessigkeit von Zerruettungsstreifen im Gebirge. (Investigations on the water permeability of shearing zones in mountains.) Die Wasserwirtschaft, 1924, p. 291–292. *Large crushed zones in rocks may weaken the structure. The water permeability depends on the content of silt (less than 10%), and clay (less than 2%) along faults. Igneous and metamorphic rocks are best for tunnels, pressure shafts, and abutments of dams.*
21. Stiny, J., Zur Frage der Abdichtung der Speicherbecken. (The question of sealing of reservoirs.) Geologie und Bauwesen, 1929, p. 239. *Use of cement for channels in carbonate rocks; mud was proposed by Ascher but results in muddy water in the reservoir at its first filling.*
22. Stiny, J., Einige Forgeerscheinungen der Spiegelabsenkungen von Speicherbecken, Wege zu ihrer Vorraussicht und Anschaetzung. (A few consequences of the lowering of the water level in reservoirs; ways of prediction and estimation.) Geologie und Bauwesen, 1929, p. 51–59. *Stable lake banks after the lowering of the water table if the banks are not steeper than their natural angle of repose. Discussion of the Achensee and the Gosausee.*
23. Stiny, J., Kuhn, K., and Winter, A., Zur Frage der Dichthaltung und kuenstlichen Abdichtung von Speicherbecken. (The question of the impermeability and sealing of reservoirs.) Wasserwirtschaft und Technik, 1936, p. 234. *A series of experiments with samples of different grain sizes and various kinds of soils.*
24. Stiny, J., and Kuhn, K., Zur Frage der Abdichtung von Speicherbecken. (On the question of sealing of reservoirs.) Geologie und Bauwesen, 1938, p. 117–119. *Minor amount of seepage may be diminished by self-sealing with suspended mud of the river. Grouting, however, still is the only safe method.*
25. Stiny, J., Die Lage des Felsuntergrundes in unseren Alpentaelern. (The location of the bedrock surface in our Alpine valleys.) Geologie und Bauwesen, 1938, p. 54–58. *The location of the bedrock surface is influenced by crustal movements and piracy of rivers.*

Swamps, thickness of the gravel deposits, and gravel terraces, are evidence of crustal movements.

26. Stiny, J., Die Gruendung von Stauwerken und die Wahl der Baustelle mit besonderer Beruecksichtigung der Ostalpen. (The foundation of dams and the selection of the site with special reference to the Eastern Alps.) Geologie und Bauwesen, 1939, p. 22–23, 50–54, 57–93. *Argillaceous limestone is good, generally more favorable than sandstone or conglomerate, but avoid pure, cave-forming limestone. Marble schist, gneiss and amphibolite are quite solid; phyllites and mica schists, however, are generally very poor. The structure of the rocks is important because: steep dip of the strata with a strike perpendicular to the axis of the valley prevents the loss of water as with sheet piles; rock with downstream dip causes seepage along the beds and the danger of possible shearing of the dam. Horizontal beds offer the best security.*
27. Stiny, J., Die geologische Lage der ostmaerkischen Speicherbecken. (The geologic location of the Austrian reservoirs.) Geologie und Bauwesen, 1939, p. 4–21. *Discussion of the different types of reservoirs, both self filling and with a pumping unit.*
28. Stiny, J., Die geologischen Grundlagen des Baues von Druckschaechten. (The geologic basis for the construction of pressure shafts.) Geologie und Bauwesen, 1940, p. 7–14. *Detailed study of the land forms gives information about the strength of the rocks and the location of the shearing zones.*
29. Stiny, J., Felsverwitterung und Talsperrenbau. (Weathering of rocks and the construction of dams.) Geologie und Bauwesen, 1941, p. 88–96. *Abutments for dams are to be located in fresh bedrock. The speed of weathering depends on the types of rock, the presence of disintegrating minerals, and vegetation. Tension cracks may be caused by rock creep. The speed of leaching of water soluble rocks is unpredictable; water under pressure can promote this process.*
30. Stiny, J., Wasserbauliche Gedankenspiele eines Geologen. (A geologist's musing relative to power dams.) Geologie und Bauwesen, 1942, p. 138–147. *About the reservoirs in the mountains, their influence on the bed load of the stream in the lower part of the river, on silting and on the formation of the valleys, and on the influence of man in nature.*
31. Stini, J.,[4] Das Gipsgebirge in der Ostmark und sein Nachweis. (Gypsum mountains in Austria and their detection.) Geologie und Bauwesen, 1942, p. 111–116. *Production of sulfuric acid by the solution of gypsum, anhydrite and other sulfide minerals. Minor amounts of gypsum in water can be detected in tunnel waters with barium chloride. The presence of the acid was missed in many tunnels and thus the damage of Portland cement was observed.*
32. Stini, J., Lehnenstollen und Lehnentunnel. (Tunneling in mountain slopes.) Geologie und Bauwesen, 1942, p. 131–133. *A minimum thickness of bedrock is required between the tunnel and the surface: in glaciated areas or young topography tunnels require a depth of 10–30 m, otherwise about 30–60 m; more depth of rock is required for pressure shafts, and still more if rock creep is observed.*
33. Stini, J., Geologische Randbemerkungen zum Krafthausbau. (Geological marginal remarks on the construction of power houses.) Geologie und Bauwesen, 1942, p. 117–122. *The construction of a power house on flood plains is either possible on avalanche debris, talus or flood sediments; building on the mountain slopes, however, is not advisable. Placement into a niche of a slope if in solid rock. Power houses underground offer best protection if in solid rock.*
34. Stini, J., Staumauerbauweise und Baugrund. (Kind of dam as related to the rocks.) Oesterreichische Bauzeitschrift, 1947, p. 97–106. *1. If the quality of the rocks is excellent and the cross-section of the valley is a) narrow—arched dams of any height, but abutments not on bedding planes or heavily jointed rock; b) not very narrow—arched or buttressed gravity dams. 2. If the quality of the rocks is medium: arched gravity dams of any height, buttressed gravity dams and small arched dams; careful grouting of the abutments is necessary. 3. If the quality of the rocks is poor: massive gravity dams and earth rolled dams only.*
35. Stini, J., Talsperrenbauten und Speicherbecken im Kalkgebirge. (Dam constructions and reservoirs in carbonate rock.) Allgemeine Bauzeitung, 1946, p. 2–9. *Pure limestone dissolves easily. Permeability for water depends on the kind of channelways and their intersections with each other. Changing width of the channels may cause self-sealing with mud or residual clay. Deeper seated parallel valleys may attract water strongly. The degree of karstification increases with the age of the land surface.*
36. Stini, J., Baugeologische Randbemerkungen zu den Hohlraumbauten der letzten Jahre in Oesterreich. (Engineering geological remarks on subterraneous excavations in Austria.) Geologie und Bauwesen, 1946, p. 1–45. *Rock of high stability—massive intrusive and high metamorphic rocks are favorable; massive sedimentary rocks, however, permit easier*

[4] Stiny, J. changed his name to Stini, J., 1942.

excavation and better stability. Rock of low stability—low metamorphic schists and mechanically crushed rocks should be avoided. Discussion of underground factories, power houses, and salt mines.

37. Stini, J., Zur Kenntnis der Tiefenrinnen. (The knowledge of deep buried channels.) Geologie und Bauwesen, 1946–48, p. 96–105. *Narrow furrows in stream beds filled with debris (bed in bed). A number of channels in the Drau valley at Maribor, 20 m wide and 10–14 m deep, and at Unterdrauburg upstream, 4–5 m deep. Origin: crustal uplift, increase of down cutting, deep connected pot holes.*
38. Stini, J., Einige Gedanken ueber den neuzeitlichen Talsperrenbau in kleineren Staaten. (Some thoughts about the modern construction of dams in smaller countries.) Geologie und Bauwesen, 1949/50, p. 143–151. *Poor, small countries should emphasize excellent quality of dam constructions, careful selection of the site, at only medium output of power.*
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1.a. continues as Allgemeine Bauzeitung from 1945 +
2. Bau und Holz, Vienna, 1949 +
3.a. Die Wasserwirtschaft, Muenchen 1913, Vienna, 1914–1934.
b. continues as Wasserwirtschaft und Technik, Vienna, 1934–1937.
4. Geologie und Bauwesen, Vienna, 1929 +
5.a. Mitteilungen der geologischen Bundesanstalt, Vienna, 1850–1938.
b. continues as Mitteilungen des Reichsamt fuer Bodenforschung, Zweigstelle Wien, Vienna, 1939–1945.
c. continues as Mitteilungen der geologischen Bundesanstalt, Vienna, 1946.
6. Verhandlungen der geologischen Bundesanstalt, Vienna.
7. Oesterreichische Bauzeitung, Vienna, 1946 +
8. Oesterreichische Wasserwirtschaft, Vienna, 1949 +
9. Schweizerische Bauzeitung, Zuerich, 1883 +
10. Wasser und Energiewirtschaft, Zuerich, 1908 +
11.a. Die Wasserkraft, Muenchen, 1921–1926.
b. continues as Wasserkraft und Wasserwirtschaft, Muenchen, 1927–1944.
c. continues as Deutsche Wasserwirtschaft, Muenchen, 1944 +
12.a. Zeitschrift des oesterreichischen Ingenieur Vereines, Vienna, 1849–1865.
b. continues as Zeitschrift des oesterreichischen Ingenieur und Architekten Vereines, Vienna, 1866–1938, 1945 +

DISCUSSIONS

CONCENTRATION OF URANIUM BY CARBON COMPOUNDS

Sir: Recent correspondence in ECONOMIC GEOLOGY (1) on the relationship between uranium and carbonaceous matter in the ores of the Colorado Plateau and elsewhere tends to complicate what in essence appears to be a relatively simple question. No geologist with field experience on the Plateau will deny that carbonaceous matter originating from the decay of plants has played a most important part in the localization of some of the richer deposits of uranium. The sole point at issue is whether this is the whole story. From a study of specimens that I collected from Temple Mountain, Utah, and elsewhere in 1953 I arrived at the conclusion (2):

> [In] the uranium fields of mid-western U. S. A., . . . so-called "wood trash" has in many instances formed the focus of rich uranium mineralization, either as carnotite or as pitchblende, derived from percolating solutions of meteoric and probably of hydrothermal character. Whether this deposition of uranium is governed by pH control, by a humic acid adsorption, by tannin precipitation, or in some other way is not yet clear; but once deposited, the primary uranium mineral has been able, by alpha radiation, to polymerize around itself in the form of thucholite the natural hydrocarbon gases such as methane that permeate and have permeated the country rock. In a single hand specimen there may, therefore, be seen a woody hydrocarbon pre-dating the pitchblende and a thucholite hydrocarbon post-dating the uranium mineralization.

Thucholite, as defined by Bowie and myself (3), is an aggregate of one or more hydrocarbons (or oxyhydrocarbons) with uraninite, the particles of the latter ranging from macroscopic to sub-microscopic size. Commonly the uraninite (exceptionally some other radioactive mineral) is seen to be partially or extensively replaced by the hydrocarbon. Many uraniferous "asphaltites" from the Plateau are indistinguishable under the microscope from thucholites derived from hydrothermal lodes and pegmatites, and there seems little reason to doubt a community of origin. "Asphaltites" and mineral oils devoid of uranium are also present in several Plateau mines; but such substances are not thucholite and it is not possible to say whether they were formed by polymerization or condensation of simpler hydrocarbons under the influence of radioactive emanations (perhaps in the presence of concentrations of radon), or whether they have some other origin.

It is stated by Gruner that "there is no field evidence that this gradual process [of polymerization of hydrocarbons by radioactive minerals] goes on today as it should since there are hydrocarbons and plenty of uranium minerals in contact with these gases and oils available." But there is as yet no field evidence that it does not go on today. Hydrocarbon gases are present

in significant quantities in the mines of the Witwatersrand and the Orange Free State in South Africa, and at Boliden and Dannemora in Sweden, where thucholite is well developed. If I recollect aright Temple Mountain itself is close to a small gas field. Is this association no more than fortuitous? It would be of interest if Gruner would name some noteworthy occurrences of primary uranium mineralization situated within an oil and gas province where the radioactive ore is *not* accompanied by hydrocarbon. No such occurrences are known to me.

Strong evidence that the distribution and chemistry of thucholite is controlled by the distribution and chemistry of pre-existing radioactive minerals has already been published (3). When Gruner claims that in the Witwatersrand ores it is difficult to find proof that the thucholite post-dates the uraninite he ignores the conclusions of mineragraphic investigations by several independent workers. In a recent study of these ores, even so doughty a syngeneticist as Ramdohr (4) admits (I have translated his words but retain his italics!) that:

It is clear beyond any doubt that the pitchblende is older than the carbonaceous matter and that the latter, when in a mobile state, migrated to the uranium.

UNIVERSITY OF ST. ANDREWS,
SCOTLAND,
August 20, 1955.

CHARLES F. DAVIDSON

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ORIGIN OF THE ROAN ANTELOPE COPPER DEPOSIT OF NORTHERN RHODESIA

Sir: In the January–February 1955 issue of ECONOMIC GEOLOGY G. Vibert Douglas criticizes the paper on the Roan Antelope Mine by G. R. Davis and earlier articles by Brummer and myself and lists five difficulties, which he requires advocates of the sedimentary syngenetic theory to explain if their views are to displace the earlier epigenetic hypothesis.

For the benefit of those who may not remember the details of these difficulties raised by Douglas, each is fully quoted before the relevant explanation.

"First—Bancroft always stressed the importance of drag folds as being associated with the ore zones. This association seemed to be remarkably exhibited at Nkana, Nchanga, Chambishi and at the Roan Antelope. If these ores are epigenetic they are found in those places exactly where they should be.

"For those who favor sedimentation it will be necessary to explain this strange fact, that the drag folds occurred where the ore had previously been deposited."

Underground work at Nkana and Roan Antelope and more detailed diamond drilling at Chambishi have demonstrated that the primary mineralization, although occurring in a shale with much drag folding, does not favor dragfolded parts of the shale. At Nkana in 1941 it was proved that the grade of the ore in the trough and crest of the folds averages exactly the same as in the squeezed limbs. This first demonstrated to the writer that the mineralization must be prefolding. Similarly at the Roan Antelope it was proved [1] that the grade of the ore in the dragfolded area was the same as in the unfolded areas adjacent. Moreover, where dragfolding becomes isoclinal on the Roan Extension the stratigraphic zonal arrangement of the minerals inherent from the original horizontal position of the beds now allows determination of attitude (top) of beds and interpretation of the folding. Again, however intense the folding, the mineralization never spreads to higher or lower stratigraphic horizons in the crest or trough of a fold, which phenomenon is commonly conspicuous in epigenetic deposits in folded strata. The observed common association between dragfolding and mineralization is probably to be ascribed to the occurrence of the mineralization in an incompetent bed, as in the case of the Roan and Nkana oreshale. Where the mineralization occurs in arenaceous beds, as at Mufulira, dragfolding is rare or absent.

There is nothing strange in the fact that dragfolds are in some cases more common where the ore had previously been deposited, for this has been noted locally at Chambishi and Nkana. The explanation by the syngenetic theory is simple—the copper has been deposited in stagnant waters close to the eastern shore line and there is a marked change of facies from a conglomerate or arkose at the shore line westward into cupriferous argillite and farther west to pyritic dolomitic shale. The argillaceous facies are prone to dragfolding and especially at the change of facies to the more competent arenaceous beds there was an accumulation of stress which would cause more intense dragfolding.

A contributory factor for small scale dragfolding is that the presence of sulphides and carbonates would promote recrystallization and gliding along laminae where they were in concentration.

"Secondly—There is no possible way to explain the Kipushi Mine where the ore occurs between the faulted ends of the Série des Mines and the fault plane, by an appeal to washed-in sediments. I have still some of that remarkable ore in our museum.

"The character of the ore in the River lode at Nchanga in my opinion is clearly epigenetic where veinlets of copper minerals run up along the shales and cross from one shale bed to another. The recent author's attempt to explain this jumping of the beds by an appeal to metamorphism. It is a difficult task."

Mineralization at the Kipushi Mine is not in the Série des Mines; the massive ore is there an obvious replacement of Kakontwe limestone, the for-

[1] By the late A. W. Howard, then geologist at Roan Antelope.

mation immediately above the tillite forming the base of the Kundelungu. In the past it has been this sweeping generalization in an attempt to force all the dissimilar disseminated copper and massive lead zinc deposits of N. Rhodesia and of the Katanga into the one genetic picture that has delayed the recognition of the syngenetic origin of the bedded disseminated deposits.

Douglas apparently does not recognize the importance of alpine type veins due to metamorphism. Most students of metamorphism realize that metamorphism involving folding and breakage in any formation allows "sweating out" and crystallization of the materials of that formation into the openings so formed. There is convincing evidence on the Copperbelt that these veins are due to lateral secretion, commonly resulting in impoverishment in sulphides for several inches of the adjacent wall rock, but leaving the more distant disseminated values intact.

"Thirdly—From polished sections and from various places underground which I saw, some twenty years ago, replacement was apparent."

Extrapolation from microscopic evidence in polished or thin section is dangerous. The small amount of replacement observed in polished section is just that which would be expected from the metamorphism of sediments containing sulphides. Similar replacements are seen in the Witwatersrand Bankets. G. R. Davis has shown that at the Roan Antelope the microscopic evidence is compatible with a syngenetic origin.

"Fourthly—The Mine Series consists of sediments that range from conglomerates and arkoses at the base to shales and dolomitic shales at upper horizons. The copper minerals are found in the shales. If the cupreous minerals are derived from a previous mineralization by erosion and transport, it seems very curious that these minerals are not with the coarse basal sediments but are associated with the mudstones on a higher horizon. The grain sizes given by Graton in a report in possession of the Roan Antelope Mine are as follows:

Relatively few grains	0.60 mm
Average grain	0.06 mm
Very many as small as	0.006 mm
Many as small as	0.0025 mm

"If the average grain diameter of chalcocite is 0.06 mm the average grain of the detrital quartz associated with it should be 0.08 mm. In other words the grain size of the sediments should be larger than that of the copper minerals which is not the case. The average grain size of sediments of the type of the Roan Shales is 0.01 mm.

If the chalcocite or chalcopyrite is the result of sedimentary processes these minerals should have been found in the conglomerates or arkoses at the base of the Mine Series. Those who favor a sedimentary origin have therefore to explain why they are in the mudstones well above the basal beds."

The difficulties here appear to be due to a misconception of the method of transport. Although the copper is believed to be derived from a previous mineralization by erosion, copper minerals were not deposited as detritals. The copper must have been transported mainly in solution, probably as sulphate or chloride, and deposition is attributed to biochemical processes in

stagnant water. Hence the copper would not be expected in the coarser sediments with heavy detritals but in the finer sediments as biochemical precipitates associated with stagnant water conditions. This is well illustrated in the case of the "ore shale" horizon at Chambishi, Roan, and Nkana where the shore line facies of coarse conglomerates and arkoses with no mineralization grades westwards into an argillaceous facies in which the copper occurs, and which further west grades into carbonate facies with pyritic mineralization.

Douglas states that the average grain size of sediments of the type of the Roan ore shale is 0.01 mm. According to Brummer [2] the average grain size of the quartz in the Roan oreshale is 0.076 mm which is very close to the figure of 0.08 mm which Douglas requires to correspond to the grain diameter of the chalcocite. Actually this cannot be used as an argument either way as undoubtedly the sulphides and detrital quartz have been completely recrystallized and the present grain sizes therefore may not correspond to the original grain sizes as deposited or precipitated.

"Fifthly—The statement that all the granite is older than the Mine Series is open to dispute. In my opinion the Nchanga granite is younger. The evidence is two-fold; at the nose of the syncline there is a tongue of granite or pegmatite cutting into the beds.

"In the footwall rocks of the long crosscut to the first shaft which was put down in 1930 or 1931 the feldspathic sandstones as I remember them show progressive feldspathization, i.e., granitization as the granite is approached."

Douglas was last on the Copperbelt in 1931. Since then 25 years of underground development and geological mapping of granite-sediment contacts have shown that all the granites exposed to date in the Copperbelt mines are older than the Katanga sediments. Of the numerous granite types, many granulated, sheared and sericitized, the Nchanga red granite looks the youngest, mainly because of its fresh pink color, coarse-grain and lack of foliation. It is cut by numerous aplite dikes. Both the pink granite and especially the aplite dikes contribute the majority of the boulders in the basal conglomerate of the Katanga System at Nchanga. Therefore there seems little doubt that the Nchanga granite is older than the Katanga System. The "pegmatite" noted at the nose of the syncline is one of many "alpine type mineralized clefts" and is apparently not due to magmatic processes.

This is not the first time that the increase of felspar towards a granite contact has been ascribed to "felspathization," when in fact the felspar is due to recrystallization of the original detrital felspar of an arkose or sandstone deposited unconformably on the granite. Regional metamorphism accompanied by complete recrystallization of all the minerals of the arkose explains the features previously attributed to felspathization.

Davis, Brummer and I probably were as strong adherents of the epigenetic theory as were Bancroft, Bateman, Davidson, Douglas, Gray and Grout. The very compelling evidence accumulated during many years of underground mapping and supplemented by microscope studies and innumerable assays caused us to switch to the syngenetic theory in opposition to the previous in-

[2] Bulletin of the Institution of Mining and Metallurgy, vol. 64, 1954–55, p. 6.

terpretation. Undoubtedly we owe a big debt to Dr. Schneiderhöhn, who was an early visitor to the Copperbelt with an expert background of knowledge of syngenetic deposits.

We would appreciate Mr. G. Vibert Douglas revisiting the Rhodesian Copperbelt when he could see for himself the extensive evidence for the syngenetic theory. The Copperbelt is only two days flying time from New York. A study of the White Pine Deposit in Michigan [3] would illustrate many features that appear to be similar to if not exact parallels of those observable on the Rhodesian Copperbelt.

W. G. GARLICK

KALULUSHI,
NORTHERN RHODESIA,
June 25, 1955

COLORADO PLATEAU URANIUM DEPOSITS

Sir: During recent years the origin of Colorado Plateau uranium deposits has been the subject of lively discussion among large numbers of geologists: What portion of the uranium was deposited with the enclosing sandstones? What portion was introduced later? What process or processes were involved?

Being a student of the Colorado Plateau deposits and having followed the development of arguments regarding origin, I am interested in five papers that appeared independently in three recent issues of ECONOMIC GEOLOGY. These papers all point out the probable importance of syngenetic processes in the formation of certain ore deposits:

Q. G. Whitshaw, The Jersey lead-zinc deposits, Salmo, B. C. (Vol. 49, 1954, pp. 521–529).—The zinc may have been derived from an argillite bed which overlies the ore-bearing limestone. Samples of the argillite contain more than 100 ppm. zinc, compared with 10 ppm. in a nearby granite. The zinc may have been concentrated by meteoric or other waters.

Stanko Mikolic, Genesis of the Witwatersrand gold-uranium deposits (Vol. 49, 1954, pp. 537–540).—Uranium was syngenetic in the carbonaceous conglomerate beds. Gold was introduced later by thermal solutions and was precipitated by the carbonaceous matter.

C. J. Sullivan, Metallic melting point and ore deposition (Vol. 49, 1954, pp. 555–574).—Association of metals, studied in terms of their melting points, suggests a syngenetic origin for 1) uranium-vanadium deposits of the Colorado Plateau, 2) copper-cobalt ores of the Rhodesia-Katanga area, 3) copper-nickel ores of the Western Macdonnell Ranges, Australia, 4) lead deposits of southeast Missouri.

G. R. Davis, The origin of the Roan Antelope copper deposit of Northern Rhodesia (pp. 575–615).—Review of existing information suggests that copper sulphide mineralization of this large deposit is syngenetic, modified by dynamothermal metamorphism acting under strong structural control.

[3] White, W. S. and Wright, J. C., 1954, The White Pine copper deposit, Ontonagon County, Mich.: ECON. GEOL., vol. 49, no. 7, p. 675–716.

Walter S. White and James C. Wright, The White Pine copper deposit, Ontonagen County, Michigan (Vol. 49, 1954, pp. 675–716). Copper in siltstone and shale appears derived from the waters in which the sediments were deposited. Copper in the sandstone was derived from nearby shale beds and was redistributed by hydrothermal activity.

All the authors cited above suggest, with greater or lesser degrees of certainty, the view that the ore metals are syngenetic. We note, though, that two types of deposits are described:

1. Deposits in which the ore metals now occur in the form and in the environment of original deposition. Example: copper deposits in the Nonesuch shale, White Pine, Michigan.

2. Deposits in which syngenetic metals were later redistributed and redeposited. Example: Roan Antelope copper deposit, Northern Rhodesia. The agent of redistribution may have been near-surface solutions, regional metamorphism, or hydrothermal solutions.

Where hydrothermal solutions pick up syngenetic metals from their original host and transfer them to another rock, somewhat removed, the deposit may be hydrothermal in appearance but the metals were made available by syngenetic processes to the depositing solutions. How should such deposits be classified? The term "hydrothermal" describes deposits formed by ascending, heated, aqueous solutions; by usage, it also *implies* that the metals have come from a deep-seated source, probably a magma.

Awareness of these considerations might provide a fortunate byproduct; namely, a change in the traditional description of ore deposits, especially as this tradition is nurtured by student theses. Having discussed the deposit and its probable hydrothermal origin, the author then describes any visible igneous bodies which might have provided the necessary solutions. If he is unfortunate in having none available within reasonable distance (i.e. a radius of 25 miles), recourse is made to invisible plutons at depth. This is the ultimate refuge of the hydrothermalist, from which he can not be dislodged.

ROBERT J. WRIGHT

530 ORCHARD AVE.,
GRAND JUNCTION, COLORADO,
July 18, 1955

REVIEWS

Experiments on the Possible Relationship Between Soil Resistivity and Dowsing Zones. By S. W. TROMP. Pp. 35; pls. 9; figs. 31. Foundation for the Study of Psycho-Physics, Vol. III, Leiden, Holland, 1955.

This report represents a summary of experiments carried out during the last five summers in the Netherlands and elsewhere upon the relationship between zones indicated by dowsing and checks by soil resistivity curves. The purpose of the experiments was to establish whether dowsing phenomena are due only to autosuggestion or whether they represent a new unknown physiological phenomenon.

The author was Professor of Geology in Cairo and in Holland, Scientific Advisor to UNESCO and is now Geological Consultant to the United Nations. He is the author of a book, *Physical Physics* (1940), that created considerable discussion.

A class of geology students was tested and a group selected who displayed dowsing phenomena. Each one, by himself, commonly blindfolded, walked along a tape in a building corridor or in a flat meadow. The point of turning of the dowsing instrument was plotted by the observer. Each dowser was unaware of the site indicated by the preceding dowser. All dowsers indicated the same zones. The surface indications of soil changes were visible. Forked sticks, loops and pendulums were used. Several hundred experiments were made. Magnetometer traverses were made over the same lanes and the curves plotted. Resistivity traverses were also made along the same lanes using a variation of the Shepard Resistivity meter with four electrodes, but mostly with two electrodes. Thirty-one figures are included showing the resistivity curves with respect to the dowsing zones. Two hundred such traverses were made. It was found that the instrument carried made no difference in the results; any kind of wood or metal served equally. All turned in the same dowsing zones. Some 500 skin electro-cardiograms of moving dowsers were made by attaching an Einthoven cardiograph to the wrists and recording on a millivolt meter the changes in skin potentials. Changes in the curves were noted as the instrument turned over a dowsing zone but no changes were recorded if the moving dowser artificially turned the stick. The cardiograph changes coincided with the dowsing zones.

Soil auger borings were made of the dowsing low-resistivity zones, which a charlatan dowser would say indicated water, and they disclosed either peat lenses or generally a change in porosity or a permeability of the soil—in a few cases a "fossil brook" overlain by dune sand. The dowsing and low-resistivity zones shifted with rainfall and raised water table. The experiments were also reversed, i.e., resistivity traverses were run, and then the same traverse was followed by a dowser uninformed of the shape of the resistivity curve. These also coincided.

Near one strong dowsing zone a house was built and a privet hedge planted across the dowsing zone. The hedge could not be made to stay alive over the dowsing zone.

The author describes in detail the nature of the experiments shown on the thirty-one figures that are reproduced depicting the resistivity curves of the traverses.

Whatever the cause of dowsing may be, one is struck by the remarkable co-

incidence of the low points of the resistivity curves over the zones indicated by the dowsers. The author thinks the nature of the experiments eliminated auto-suggestion and that some type of physiological phenomenon is indicated.

A. M. B.

Geology, Principles and Processes. By WILLIAM H. EMMONS, GEORGE A. THIEL, CLINTON R. STAUFFER, and IRA S. ALLISON, 4th edition. Pp. 638; figs. 519. McGraw-Hill Book Company, Inc., New York, 1955. Price, $6.50.

This well known text book is planned for students who wish a cultural course in geology, and as a sound basic course for those who plan to major in earth sciences. New material added to this fourth edition consists of a more complete presentation of chemical weathering, a new chapter on wind work, expansion of erosional processes in desert areas, a classification of soils, permafrost, shore-line erosion, mobility of rocks in mountain making, and an expanded section on mineral resources. The last consists chiefly of brief discussions of the non-metallic mineral products and a few pages on metallic ores in which is a list of ore minerals, mineral veins, sources of vein-forming waters, pegmatites, contact deposits, magmatic segregations, sedimentary deposits, weathering of ores and sulfide enrichment. Three appendices treat of maps—topographic and structural; map symbols, columnar and structure sections and geologic time.

The subject matter of the book follows the customary content of elementary text books of physical geology, except that elements, compounds, minerals and rocks appear as Chapter 3. Several new photos are included.

Geography of the Northlands. Edited by GEORGE H. T. KIMBLE and DOROTHY GOOD. Pp. 534; pls. 75; figs. 47; tbls. 15. American Geographical Society Special Publication No. 32, American Geographical Society and John Wiley and Sons, New York, 1955. Price, $10.50.

Geography of the Northlands is made up of contributions by fifteen authors with northern latitude acquaintance. These areas, formerly remote, are now fairly accessible and have become much better known through the use of the airplane and because of the numerous military and civilian surveys of these distant lands. This book, the first of its kind in many years, gives detailed, authoritative knowledge of the arctic regions and includes the results of recent field research.

The list of authors is as follows: P. T. Baird, J. B. Bird, P. Dansereau, M. J. Dunbar, Dorothy Good, S. Haden-Guest, F. K. Hare, G. H. T. Kimble, J. R. Mackay, Svenn Orvig, Ivar Skarland, J. J. Teal, Jr., J. P. Tremblay, P. E. Uren, Bogdan Zaborski. Of these, five from McGill University, one each from the Universities of Aberdeen, Michigan, British Columbia and Alaska, and the others from the World Geography of Petroleum and of Forests, Twentieth Century Fund, Arctic Institute, Geographical Review, Institute of Northern Agricultural Research, and the Canadian Defense Research Board.

The subjects are divided into two parts—Systematic Studies and Regional Studies. The first includes physiography, water masses and ice cones, weather and climate, biogeography, marine life, populations, transportation, wealth of the northlands, and political and strategic aspects. The regional studies include Alaska, Canada, Greenland, Iceland, Scandinavia, Svalbard and Russia. Two appendices cover outstanding discoveries and plant and animal names. History, descriptions and resources are given under each section.

The book is well organized, generally well written and sufficiently illustrated

with maps, charts and photographs. It should prove to be an excellent reference work for geographers, geologists and mining men.

Geology in Engineering. By JOHN R. SCHULTZ and ARTHUR B. CLEAVES. Pp. 592; figs. 208; tbls. 14. John Wiley and Sons, New York, 1955. Price, $8.75.

Geology in Engineering serves a dual purpose—it serves to acquaint the engineer with geologic principles and methods, and to acquaint the geologist with engineering practices relating to geology. It integrates geology and engineering.

The geologic subjects covered are those with which engineers come in contact, namely: minerals, rocks, structure, groundwater, weathering, erosion, land forms, shore lines, glaciation, frost action, landslides, volcanoes, earthquakes and historical geology. The discussions of these lay emphasis on engineering aspects. In addition, there are chapters on geologic maps and sections, and aerial photographic interpretation of soils.

The engineering features of particular interest to geologists are soil mechanics, subsurface exploration, dams and reservoirs, tunnels, highways and airfields and concrete aggregates. Various engineering designs are pictures.

The book is clearly written and well illustrated and is fully up to date. It combines geology and engineering excellently. We consider it to be the most up-to-date and the best book on engineering geology that we know of.

Physical Geology. By L. DON LEET and SHELDON JUDSON. Pp. 466; illus. Prentice-Hall, Inc., New York, 1954. Price, $6.75.

This interesting elementary text book immediately catches the eye by the size of its pages ($6\frac{3}{4} \times 9\frac{3}{4}$) and its interesting photographs and striking drawings. The 18 chapters cover the customary subjects, treated in elementary text books on geology, except that Chapter 2, Materials of the Earth, is largely chemistry and deals with matter, mass, weight, atoms, elements, isotopes and energy. The chapter concerning the solar system and the age of the earth is placed toward the end of the book (Chapter 15). Each chapter ends with a summary and a list of selected references, both of which are welcome additions. Of particular interest and value to students is a fine glossary of practically all of the technical terms used in the book, including mineral and rock names. There are five appendices: A, Electrical Configuration of Elements 39–98, with an alphabetical list of the elements; B, Powers of Ten, with examples of distances and sizes; C, Geologic Divisions of Time; D, Minerals; E, Topographic Maps.

The book is written in an easy and interesting style and holds the interest of the reader. The size of the page permits advantageous use of larger illustrations than customary. The arrangement of subject matter is well integrated to carry the reader from one step to the next. It should prove to be one of the outstanding text books of physical geology.

Handbook Australia and New Zealand. Edited by MALCOLM GLEN. Fifth Empire Mining and Metallurgical Congress, 1953. Pp. 255; illus. Australian Institute of Mining and Metallurgy, Melbourne, 1953.

This is the eighth volume to appear as a part of the Fifth Mining and Metallurgical Congress of Australia and New Zealand, 1953, under the general editorship of M. R. McKeown. This volume contains the preliminary matter of the congress, abstracts of Volumes I to VI, and nine general articles. These consist of the geography, climate, and peopling of Australia, its development, territories,

principal mineral producers, technical education and research, technical and scientific societies, and mining education.

The main part of the volume (181 pages) is given over to sections relating to each state of Australia and of New Zealand. Under each are subsections on (a) Geology, (b) General Development, (c) Mining and Metallurgical Events of Importance, (d) Power Resources and Installations, (e) Principal Mineral and Metal Producers, and Catalogues of Australian and New Zealand publications. Many maps, photographs and tables supply additional information. It is a very convenient and concise reference book about Australia and New Zealand.

World Economic Geography. By EARL B. SHAW. Pp. 582; figs. 339; tbls. 12. John Wiley and Sons, New York, 1955. Price, $6.50.

The author has divided his book into five parts: 1. Economic Geography, Meaning and Approaches; 2. The Forest, Fish and Animal Industries; 3. The World's Agriculture; 4. Manufacturing and Trade; 5. Population. In Part I, the author emphasizes the fundamental principles of geonomics and the five chapters include four approaches to the subject. The commodity approach is illustrated by a study of the economic geography of rubber (Chap. 2). The economic regions of Guatemala are analyzed to illustrate the regional approach (Chap. 3). The commercial corn-mixed farming belt presents an activity approach (Chap. 4). The world's mineral industries are examined to stress the principles approach in Chapter 5. Here the various methods of mining and oil extraction are described and pictures and drawings of plants are given. Nine charts are included depicting relative country production of as many metals. There are brief paragraphs on the metallic content of ore, technical advance, ease of exploration, demand, transportation, where minerals are found, and mineral resources. The "principles approach," however, seems hidden.

In Part 3, there are eight chapters dealing with agriculture in different climatic belts, each followed by a discussion of the value of each region to world powers.

Throughout the book one notes that the author has injected the business viewpoint in the text. He gives the physical and man-made factors that have contributed to the economic growth of countries. He gives the reader a sound knowledge of world economic geography.

BOOKS RECEIVED

KURT SERVOS

U. S. Geological Survey—Washington, D. C., 1955.

Prof. Paper 236-B. Foraminifera from the Arctic Slope of Alaska. Part 2, Jurassic Foraminifera. HELEN TAPPAN. Pp. 21–90; pls. 6–28; figs. 3–9; chart 1. Price, $1.50. *This first Lower Jurassic foraminiferal fauna, including 36 new species, from the western hemisphere correlates with the Liassic of Europe.*

Prof. Paper 263. Floras of the Pocono Formation and Price Sandstone in Parts of Pennsylvania, Maryland, West Virginia, and Virginia. CHARLES B. READ. Pp. 32; pls. 20; fig. 1. *History of views on Mississippian strata precedes description of 23 new species.*

Prof. Paper 264-F. Permafrost and Ground Water in Alaska. DAVID M. HOPKINS, THOR N. V. KARLSTROM, and others. Pp. 113–146; pls. 30–44; figs. 5–11. Price, $1.00. *Permafrost studies include the use of photointerpretation techniques.*

Prof. Paper 264-H. Studies of Some Early Tertiary Red Conglomerates of Central Mexico. JOHN D. EDWARDS. Pp. 153–185; pls. 45–47; figs. 17–40; tbls. 12. Price, $1.25. *Two geologic maps, 1 in. = 500 m.*

Prof. Paper 274-A. Volcanic-Rich Middle and Upper Eocene Sedimentary Rocks Northwest of Rattlesnake Hills, Central Wyoming. FRANKLYN B. VAN HOUTEN. Pp. 14; pls. 3; figs. 3; tbls. 2. Price, 65 cts.

Bull. 969-C. A Geologic Reconnaissance of Parts of Beaverhead and Madison Counties, Montana. M. R. KLEPPER. Pp. 55–85; pl. 1. Price, 60 cts. *Area contains extensive nonmetallic economic mineral deposits of which a sillimanite deposit with possible commercial significance was found in 1948.*

Bull. 1015-E. Strippable Lignite Deposits, Slope and Bowman Counties, North Dakota. ROY C. KEPFERLE and WILLIAM C. CULBERTSON. Pp. 123–182; pls. 12–20; figs. 18–28; tbls. 4. Price, $1.00. *Economic lignite beds are in the Fort Union fm. of Paleocene age; thicknesses vary from 5 to 40 feet. Heating value is about 6,300 Btu.*

Bull. 1015-F. Geology and Coal Resources of the Henryetta Mining District, Okmulgee County, Oklahoma. R. J. DUNHAM and J. V. A. TRUMBULL. Pp. 183–225; pls. 21–24; figs. 29–32; tbls. 3. Price, $1.00. *Total remaining coal reserves are estimated at 275 million tons. Coal occurs in the Senora fm. (Pennsylvanian) in two beds with average thicknesses of 16 in. (Morris bed) and 25–36 in. (Henryetta bed).*

Bull. 1015-G. Zinc-Lead-Copper Resources and General Geology of the Upper Mississippi Valley District. ALLEN V. HEYL, ERWIN J. LYONS, ALLEN F. AGNEW and CHARLES H. BEHRE, JR.; Illinois information by H. B. WILLMAN and R. R. REYNOLDS. Pp. 227–245; pls. 25–26; figs. 33–34; tbl. 1. Price, 70 cts. *Deposits are mostly zinc in veins, replacements, and impregnations, along shears, faults, and bedding-plane faults associated with small folds, all in Middle Ordovician limestones. Chief primary minerals are quartz, dolomite, pyrite, marcasite, sphalerite, galena, chalcopyrite, barite and calcite.*

Bull. 1036-A. Rapid Field and Laboratory Method for the Determination of Copper in Soil and Rocks. HY ALMOND. Pp. 8; fig. 1. Price, 10 cts. *From 60 to 80 determinations can be made per man-day in the field.*

Water-Supply Paper 1260-C. Floods of 1952 in the Basins of the Upper Mississippi River and Red River of the North. Pp. 529; pl. 1; figs. 36–71; tbls. 7. Price, $1.00.

Water-Supply Paper 1313. Compilation of Records of Surface Waters of the United States through September 1950. Part 9, Colorado River Basin. Pp. 749; pl. 1; figs. 2. Price, $2.75. *Data summarize streamflow records in the Colorado River basin.*

Water-Supply Paper 1297. Ground Water of the Lower Lake-Middletown Area, Lake County, California. J. E. UPSON and FRED KUNKEL. Pp. 83; pl. 1; tbls. 5. Price, 55 cts.

Water-Supply Paper 1298. Reconnaissance of Geology and Ground Water in the Lower Grand River Valley, South Dakota. P. C. TYCHSEN and R. C. VORHIS. Pp. 33; pls. 2; figs. 3; tbls. 4. Price, 50 cts.

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1955.

RME-3020. Annual Report for April 1, 1954 to March 31, 1955. JOHN W. GRUNER and DEANE K. SMITH, JR. Pp. 37; pl. 1. *The first of four papers shows that similar geologic processes operated in producing concentrations of "black U*

ores" in rocks that range from Triassic to Eocene. Coffinite is probably $USiO_4$, $c/a = 0.899$.

Eighteenth Semiannual Report. Pp. 160. *Activities and research progress of the AEC includes notes on the Atoms-for-Peace Conference.*

International Conference on the Peaceful Uses of Atomic Energy. The Natural Occurrence of Uranium and Thorium. PAUL F. KERR. Pp. 138; figs. 49; tbls. 6. *This comprehensive summary was provided for the non-geological members of the conference in Geneva. The geochemistry of U and Th is thoroughly reviewed by means of collation from the recent literature.*

Mineralogy of Some Japanese Manganese Ores. DONALD E. LEE. Pp. 64; figs. 7; tbls. 25. Stanford University Press, Univ. Ser., Geol. Sci. Vol. V, Stanford, 1955. Price, $1.50.

Glossary of Selected Geologic Terms, with Special Reference to Their Use in Engineering. W. L. STOKES and D. J. VARNES. Pp. 165. Colo. Sci. Soc. Proc. Vol. 16, Denver, 1955. Price, $3.50 (Cloth). *A technical glossary containing 2,670 entries of geologic terms (excluding formal stratigraphic names) with full explanations; extremely valuable reference book for geologists and engineers.*

Soil Warming by Electricity. R. H. COOMBES. Pp. 116; pls. 16. Philosophical Library, New York, 1955. Price, $4.75. *Gives techniques of warming soil by buried electric cables and results on flowers, vegetables and fruits.*

Climates in Miniature. T. BEDFORD FRANKLIN. Pp. 137; pls. 8; figs. 10; tbls. 11. Philosophical Library, New York, 1955. Price, $3.75. *The author, a nature lover, tells how beasts, birds and plants react to local climates and environments; how they keep warm in winter and how to measure soil temperatures and protect against frost damage.*

Der Pluton von Loch Doon in Südschottland. GERHARD OERTEL. Pp. 107; 4 maps; figs. 45; tbls. 15. Geotektonische Forschungen, E. Schweitzerbart'sche Verlag., Stuttgart, 1955. Price, 27 DM. *Detailed petrologic, petrographic, petrofabric and structural study of Scottish plutons accompanied by three maps of the structure and one of the geology.*

California Division of Mines—San Francisco, 1955.

Special Rept. 41. Geology and Mineral Deposits of the Angels Camp and Sonora Quadrangles, Calaveras and Tuolumne Counties, California. JOHN H. ERIC, ARVID A. STROMQUIST and C. MELVIN SWINNEY. Pp. 55; figs. 21; pls. 4. Price, $3.75. *Gold (with Ag and Cu as byproducts) is the most important mineral commodity in this central part of the Mother Lode. The fault system, rather than the host rock, probably was the chief controlling factor in ore deposition. Two geologic maps, 1:24,000.*

Publications of the California State Division of Mines (to July 1, 1955). Pp. 154. *Complete bibliography includes a list of depository libraries showing holdings of Division of Mines publications.*

California Journal of Mines and Geology, Vol. 51, No. 3. Pp. 203–289; pl. 1; figs. 28. Price, $1.00. **Manganese Deposits on the Northeast Pacific Sea Floor.** ROBERT S. DIETZ. *Extensive deposits of Mn nodules on the deep sea floor contain relatively high concentrations of Co, Cu and Ni.* **Mines, Mineral Resources, and Mineral Industries of Marin County.** WILLIAM E. VER PLANCK. *Nonmetallic minerals valued at more than one million dollars were produced in Marin County during 1953. Geologic map, 1:126,720.*

The Ground-Water Resources of the Areas in the Vicinity of the Interchanges on the East-West Ohio Turnpike. JAMES J. SCHMIDT and ALFRED G. WALKER.

Ohio Department of Natural Resources, Inf. Circ. No. 5, Columbus, 1954. Pp. 65; pls. 16; tbls. 16.

Illinois Geological Survey—Urbana, 1955.

Illinois Petroleum 72. Oil Resources and Possibilities in Illinois. ALFRED H. BELL. Pp. 12; figs. 6. *Prognosis of 1.75 billion bbl oil as future production is based on past geologic experience.*

Circ. 198. Groundwater Possibilities in Northeastern Illinois. R. E. BERGSTROM, J. W. FOSTER, LIDIA F. SELKREGG and W. A. PRYOR. Pp. 24. Mineral Industries of Illinois. Map, 1:500,000.

North Dakota Geological Survey—Grand Forks, 1955.

Bull. 29. Subsurface Correlations of the Cretaceous Greenhorn-Lakota Interval in North Dakota. DAN E. HANSEN. Pp. 46; pls. 2; figs. 10; tbls. 3.

Rept. of Inv. 19. A Magnetometer Survey of the Keene Dome, McKenzie County, North Dakota. ALBERT G. OPP. 1 sheet; figs. 3.

Circ. 112. Summary of the Carter Oil Co., Ed. Lockwood No. 1, Dunn County. CLARENCE G. CARLSON. Pp. 12.

Circ. 113. Summary of the Phillips Co., Hoehn A-1, McKenzie County. CLARENCE CARLSON. Pp. 13.

Circ. 114. Summary of the California Co., Rough Creek Unit No. 1, McKenzie County. JOHN L. HAINER. Pp. 13.

Circ. 115. Summary of the Calvert Exploration Co. & Leonard Ward, State A No. 1, Renville County. CLARENCE CARLSON. Pp. 5.

Circ. 116. Summary of the J. P. Owens-Rosie Schann No. 1, Pierce County. CLARENCE CARLSON. Pp. 4.

Circ. 117. Summary of the Calvert Exploration Co., C. C. Nitschke No. 1, McIntosh County. JOHN L. HAINER. Pp. 3.

Circ. 118. Summary of the McLaughlin & Ericson-Walz & Westby No. 1, Bottineau County. JOHN L. HAINER. Pp. 3.

Circ. 119. Summary of the Calvert Exploration Co., National Bulk Carriers, Stadium No. 1, Benson County. CLARENCE CARLSON.

Circ. 120. Summary of the Turner Oil Co., Theodore Belanus No. 1, Pembina County. DAN E. HANSEN. Pp. 2.

Circ. 121. Summary of the Lion Oil Co., Carl & Sylvia Skarphol No. 1, Bottineau County. JOHN L. HAINER. Pp. 4.

Production Statistics and Engineering Data on Oil in North Dakota, First Half, 1955. Pp. 93.

Uranium, the World's Expanding Frontier. ARMAND EARDLEY et al. Pp. 111; figs. 24. Utah Geological and Mineralogical Survey, Uranium Research Center, P. O. Box 1925, Salt Lake City, 1955. *The geochemistry, production and economics of U are reviewed for the layman.*

West Virginia Geological Survey—Morgantown, 1955.

Bull. 11. Oil and Gas Report and Map of Pleasants, Wood, and Ritchie Counties, West Virginia. OSCAR L. HAUGHT. Pp. 21.

Bull. 12. Oil and Gas Report and Map of Marshall, Wetzel, and Tyler Counties, West Virginia. OSCAR L. HAUGHT. Pp. 49.

Geologia de Fronteras. TELASCO GARCIA CASTELLANOS. Pp. 38; figs. 13. Universidad Nacional de Cordoba, Argentina, 1954. *The placement of boundaries be-*

tween nations is significantly ramified by geologic phenomena and processes, including ore deposits.

Geology and Mineral Deposits of the Tennant Creek Gold-Field, Northern Territory. J. F. IVANAC. Pp. 164; pls. 44; figs. 16; tbls. 6. Bureau of Mineral Resources, Geology and Geophysics, Bull. 22. Canberra, 1954. *Ore is gold-bearing hematite-rich brecciated mudstone or shale (Precambrian). Nearly 200,000 tons, averaging 18.1 dwt. per ton, have been produced and an equivalent amount constitutes reserves.*

Societe Geologique de Belgique—Liege, 1954–55.

Manifestation Paul Fourmarier. Pp. 39. *Tribute to the dean of Belgian geologists.*

Annales, Tome 78, Nos. 8, 9 and 10. Pp. 107; pl. 1; figs. 23; tbls. 3

Water Supplies of the British Virgin Islands. P. H. A. MARTIN-KAYE. Pp. 69. Georgetown, Demerara, British Guiana, 1954. Price, $1.00.

Bibliografia Geologica de Chile (1927–1953). J. MUÑOZ CRISTI and J. KARZULOVIC KOKOT. Pp. 121. Universidad de Chile, Instituto de Geologia Pub. No. 5, Santiago, 1955. *The bibliography of 608 titles is annotated.*

Bull. No. 6, Direction des Mines, Gouvernement Général de l'Afrique Equatoriale Française, Paris, 1954. Pp. 100; pls. 4; figs. 11; charts 4. **Recherches Géologiques au Gabon Central.** BORIS CHOUBERT. *Deals with metamorphic rocks in central Gabon.* **Pélécypodes Marins de la Formation de Pala-Lama (Territoire du Tchad).** ANDRÉ CHAVAN. *Middle Cretaceous pelecypods.*

Progress Rept., 1954. Pp. 88; fig. 1. Geological Survey of Great Britain, London, 1954. Price, 3s. 6d.

Die Physikalisch-Technischen Fortschritte der Geoelektrik. MAX MÜLLER. Pp. 147; figs. 75. Istituto Geofisico Italiano, Milano, 1952. Price, 4500 Lire. *Comprehensive summary of electricity in geophysical methods is based primarily on mathematics.*

Geological Survey of Japan—Hisamoto-cho, Kawasaki, 1955.

Explanatory Text of the Geological Map of Japan. Ogaki (Kyoto-7). HIROSHI ISOMI. Pp. 30. *The Akasaka limestone (Middle Permian) and a small hematite deposit constitute economic minerals. Geologic map, 1:50,000. Text in Japanese, résumé in English.*

Explanatory Text of the Geological Map of Japan. Iwanai (Sapporo-27). OSAMU HIROKAWA and MASARO MURAYAMA. Pp. 34. *Small orebodies of Cu and of Th are lenticular or stratified; S is associated with a hot spring. Geologic map, 1:50,000. Text in Japanese, résumé in English.*

Prospecting for Radioactive Minerals in New Zealand. L. I. GRANGE. Pp. 28; fig. 1. New Zealand Geological Survey, Wellington, 1955. *This layman's guide contains a geologic map of North Island, 1:2,534,400.*

The Nigerian Coalfield. The Geology of Parts of Onitsha, Owerri and Benue Provinces. A. SIMPSON. Pp. 85; pls. 5; figs. 19; tbls. 24. Geological Survey of Nigeria Bull. 24, Zaria, 1954. Price, shs. 10/16. *More than 600,000 tons of coal are produced annually. 4 geologic maps.*

Trans. Vol. XVI, Pt. II. Pp. 93–227. Edinburgh Geological Society, Edinburgh, 1955. Price, shs. 12/6. *Six papers deal with various aspects of Scottish geology.*

Revista de Minas e Hidrocarburos, Ano VI, Num. 18. Pp. 114. Ministerio de Minas e Hidrocarburos, Caracas, 1955. *One report summarizes mineral industry and economics; another deals with agriculture.*

SCIENTIFIC NOTES AND NEWS

THE ILLINOIS STATE GEOLOGICAL SURVEY held its 50th Anniversary at Urbana-Champaign on October 11, 1955.

AMORN METHIKUL and DAMNER SITHIPRASASNA, geologists with the Royal Department of Mines, Bangkok, Thailand, and IGNACIO ANTONIO, geologist with the Philippines Bureau of Mines, are in the United States participating in the government technical assistance program.

W. C. LACY, chief geologist for Cerro de Pasco Corp. at Oroya, Peru, has joined the faculty of the University of Arizona as a professor of geology.

GEORGE N. BOURRET, chief geologist for the Utah Construction Co., returned to the United States after an inspection of various mining properties in Peru.

ALLEN F. AGNEW, formerly in charge of the Wisconsin and Iowa zinc-lead projects for the USGS, has accepted a position as associate professor of geology at the University of South Dakota.

GLENN WATERMAN, resident geologist at Chuquicamata, Chile, for Anaconda Co., has been named geologist at the Salt Lake City, Utah office, exploration division of the firm.

JOSEPH W. BERG, JR., formerly assistant professor of geophysics, University of Tulsa, Okla., has accepted the position of assistant professor in the department of geophysics, University of Utah, Salt Lake City.

H. W. NORMAN, AEC Geologist for the Spokane area, has resigned to become geologist for Daybreak Uranium and for Morning Sun Uranium, Inc. Norman is succeeded by DONALD HETLAND, a University of Washington graduate geologist.

MORRIS M. LEIGHTON, Chief Emeritus of the Illinois State Geological Survey at Urbana, will serve as general chairman of the 41st annual meeting of the American Association of Petroleum Geologists, to be held at the Conrad Hilton Hotel, Chicago, on April 23–26, 1956. As in past years, this will be a joint meeting with the Society of Economic Paleontologists and Mineralogists. The theme of the 1956 session will be "Sealing Factors in Oil and Gas Reservoirs." The technical program will present a series of sessions and panel discussions dealing with the many factors that operate to halt the subsurface migration of oil and gas or to place an effective seal on commercial pools.

FRANK PRESS has joined the faculty of the California Institute of Technology as professor of geophysics.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS held its 25th annual meeting at Denver, Colorado, October 3–6. Some 53 papers were presented.

THE MICHIGAN COLLEGE OF MINING AND TECHNOLOGY, Houghton, Michigan, will hold an institute on Lake Superior Geology at the college on May 11–12, 1956. The theme will be "Geological Exploration." THE MICHIGAN GEOLOGICAL SURVEY and the EXPLORATION SUBSECTION of the UPPER PENINSULA SECTION of the A.I.M.E. are cooperating with the college in presenting the institute. Theoretical and practical developments in techniques of ore search on both sides of the international border will be featured. Geochemical, geophysical, geobotanical and pho-

togeological approaches in mineral deposits research will be presented by specialists from the United States Geological Survey, the Geological Survey of Canada, the Ontario Department of Mines and from industry. Field trips will follow the conference. Convener of the institute is Dr. A. K. SNELGROVE, head of the Department of Geological Engineering at Michigan Tech.

RUSSELL GIBSON has returned from Iran to his home in Belmont, Mass.

ROBERT M. GARRELS is now in residence at Harvard University as associate professor of geology. He was formerly head of the Solid State group in the Geochemistry and Petrology branch of the U.S.G.S.

EDGAR E. N. SMITH is chief geologist at Uranium City, Sask., for Eldorado Mining and Refining, Ltd.

ROBERT C. STEPHENSON, Woodward & Dickerson, Inc., Philadelphia, has been appointed executive director, American Geological Institute, Washington, D. C. From 1946 to 1952 Mr. Stephenson was assistant state geologist of Pennsylvania. He succeeds CHARLES HUNT, who is returning to the USGS.

P. J. SHENON and R. P. FULL, mining geologists of Salt Lake City, have established a branch office of their firm in the Munro-Morrison Bldg., Grand Junction, Colo.

E. J. PERRY, who was with Giant Yellowknife Gold Mines, Ltd., Yellowknife, N. W. T., Canada, has accepted a position with Eldorado Mining & Refining, Ltd., Beaverlodge Operation, Sask.

EUGENE W. WHEELER is a junior geologist with Andes Copper Mining Co., Potrerillos, Chile. Mr. Wheeler was with the Anaconda Co., Butte, Mont.

ROBERT G. REEVES, geologist, USGS, Reno, Nev., has been assigned to Defense Minerals Exploration work, USGS Pacific Coast Center, Menlo Park, Calif.

CALAMUR MAHADEVAN, a geologist from India, has been sent to Brazil on a technical assistance mission for the United Nations Education, Scientific and Cultural Organization (UNESCO). He will be on leave of absence from his post as head of the geology department at Andhra University, Waltair. Professor Mahadevan will survey mineral resources in the Amazon Valley and will be stationed at Manaus.

AGATIN T. ABBOTT, assistant professor of geology in the college of mines at the University of Idaho, has accepted the position of associate professor and head of the department of geology and geophysics at the University of Hawaii.

GORDON J. MACDONALD has been promoted to associate professor of geology at the Massachusetts Institute of Technology.

WILLIAM W. HAMBLETON this fall assumed the duties of assistant state geologist and assistant director of the State Geological Survey, University of Kansas. He will also remain on the faculty of the Department of Geology which he joined in 1951. Dr. Hambleton's new office in the Mineral Resources Building at K. U. joins that of Dr. Frank C. Foley, state geologist and director of the Geological Survey.

PHILIP D. WILSON, consulting mining engineer and geologist, has been elected a director of Callahan Zinc-Lead Co.

W. E. WRATHER, Director of the U. S. Geological Survey, was presented with the Distinguished Service Award of the Department of the Interior, at a small ceremony at his home on September 21st, by Felix Wormser, Assistant Secretary of the Interior.

TAKAO SAKAMOTO, professor of geology at the University of Tokyo, is engaged in a technical assistance mission for the United Nations Educational, Scientific and Cultural Organization (UNESCO) in Brazil. On leave of absence from his post in Tokyo, Professor Sakamoto will work on a survey of mineral resources in the Amazon Valley. He will join Calamur Mahadevan (mentioned above) in this work.

W. T. JOHNSTON, chief of the foreign division, U. S. Geological Survey, has been on a tour of inspection of the various geological missions now operating in Mexico, Cuba, Brazil, Bolivia, Chile and Peru.

THOMAS L. KESLER, chief geologist of the Foote Mineral Co., has been making a series of trips to keep abreast of developments in the lithium-ore districts throughout Canada.

EMMONS MEMORIAL FELLOWSHIP

The S. F. Emmons Memorial Fellowship in Economic Geology is available for the academic year 1956–57, with a stipend of $1,600.00. Applications and accompanying testimonials should be submitted not later than February 15, 1956.

Applicants should be qualified by training and experience to investigate some problems in Economic Geology and should submit a definite statement of the problems to the Committee, under whose supervision the work may be undertaken at any institute approved by them. The Fellow must give entire time to the problem, which may be used for a doctoral dissertation. Application blanks may be obtained from Alan M. Bateman, Yale University, H. E. McKinstry, Harvard University, Paul F. Kerr, Columbia University, or the Secretary, Columbia University.

THE INSTITUTE OF PETROLEUM

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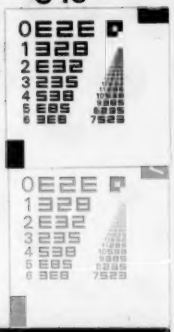
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